TECHNIQUE OF MODERN WELDING

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TECHNIQUE OF MODERN WELDING

BY

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Authorized Translation from the Second German Edition, with additions and revisions by Prof. Bardtke, by

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PREFACE FROM SECOND GERMAN EDITION

Four years have passed since the appearance of the first edition. In this short space of time welding technology has advanced with such rapid development that the first edition can be said to have been superseded and to be out of date. Not only have new equipments and machines embodying considerable improvements been put on the market in the meantime, and not only have new processes been developed, filler materials improved and their fields of application extended, but in addition, due to thorough scientific research, points of view have changed in many cases. Hence it appeared advisable to undertake a complete revision and extension of the book, and this has now been brought before the public.

In this revision, I have also kept in view the experience which has been gained in the Welding Research Department of the repair works of the German State Railways at Wittenberge, which is under my charge. In addition it was necessary, to a great extent, to analyse the current literature which did not exist during the preparation of the first edition.

In order to limit the extent of the book, I have in most cases only selected the results of other publications. The reader can look up further details in the references given.

The comprehensive survey of the first edition has been retained in the revised edition, so that the book not only offers to the welding engineer an excellent survey of the field of welding technique, but may also be used for the equally important training of the welder, foreman, and welding student. It may also be used as a basis for

anyone desirous of instructing himself, and as a curriculum in technical schools.

I hope that the new edition will obtain the same favourable reception as the first edition. In conclusion I wish to express my thanks to Dr. Ing. Matting, my colleague in the Technical Welding Research Department, for his critical review of the manuscript.

P. Bardtke.

Wittenberge,
October, 1931.

TRANSLATOR'S PREFACE

It is no exaggeration to say that in the field of engineering technology the greatest single development which is taking place to-day is in " Welding ".

Since the war every effort has been made to eliminate the rule of thumb methods and the haphazard technique which have characterized welding in the past, and the steady output of well informed papers and research work testify to the increasing participation of the trained research worker in this important branch.

Due to the greater degree of centralization which exists in American and German welding circles, the results of new work are more readily available to the welding engineer and operative than they are in Britain, and practice tends to follow experimental work much more closely.

For this reason a book by the Director of the Welding Repair Workshops and the Welding Research Department of the German State Railways should provide that combination of practical experience and theoretical knowledge which is to-day so necessary when new applications of the technique are being considered or when old methods are being displaced or improved.

In presenting a translation of the second edition of Professor P. Bardtke's book to those interested or actively engaged in Welding work, I should like to mention that, during the preparation of the English edition, the author revised certain sections of the original second edition and amplified others in the light of the most recent results. By indicating the more important gaps in our knowledge

and the lines on which development in the future is likely to take place, he has ensured that the book will remain of valuable assistance to the student, engineer, draughtsman, and operative for many years to come.

H. KENNEY.

NORTON-ON-TEES,
September, 1933.

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PART I.—WELDING PROCESSES

CHAPTER I

Introduction

1. Historical Development of Welding Technology.

Up to a few decades ago, welding was understood to mean the joining, under the press, of two pieces of iron which had been heated in the fire to a plastic state. In other words, the only process known was that which had been practised for centuries, the so-called forge or hammer welding. Along with this, water-gas welding, in which the water-gas flame replaced the smith's fire as a source of heat, appeared at the end of the previous century. In the foundry another process was used which was termed the cast welding process by technicians. This consisted of adding molten iron in a mould provided with a runner at the point where the casting had not flowed, or where a broken place had occurred. This iron was allowed to run in until the iron round the edge of the article was fluid, and then the runner was blocked up and the iron cooled in the mould. We have already met the forerunner of our present-day fusion welding. The process, however, was expensive and unreliable and was, therefore, only used on a small scale in large foundries, when it was hoped to reclaim a faulty article.

In the year 1887 the Russian Benardos, in St. Petersburg, succeeded in carrying out welds on cast iron, wrought iron, and steel by means of the electric arc. He was followed shortly afterwards in 1889 by Zerener, and in 1890 by Slavianoff, who also used the heating effect of the electric arc for new processes for welding purposes.

Although these inventions excited considerable attention, nevertheless these beginnings of electric arc welding halted in their development, since numerous faults and unsatisfactory welds were

experienced, on account of faultily designed welding machines and unsuitable filler materials. Consequently little was heard of electric welding. In general, it was treated by a few welders as a secret art, which they would not disclose to anyone under any circumstances; electric fusion welding was not the common property of technology.

In the first few years of the twentieth century a new welding process arose which, from the beginning, gave better results and which thrust electric welding into the background. This was the so-called autogenous welding.*

In the year 1892 acetylene was accidentally discovered in Spray (North America). At that time it was exclusively used for illuminating purposes. Shortly afterwards success was achieved in putting on the market oxygen compressed in cylinders as a commercial commodity, and attempts were made to fuse and weld iron by an explosive mixture of acetylene and oxygen. Only the former was achieved since the iron burned immediately and no union of the metal edges could take place. Only in 1900 was the first torch, which was suitable for welding, constructed in England. In the following years this process developed quickly, torches were continually developed and the quality of the weld improved, so that, in the early years of this century, satisfactory welds of all kinds could be carried out.

At the same time, electric-resistance welding appeared. Even in the year 1907, this process was used to a wide extent, in the plate and light steel trades.

These new welding processes only blossomed forth and developed during the war years, when people in all countries were compelled to make damaged equipment once more usable in the shortest time. Welding was also found to be very economical, since scarce metals, which were necessary for carrying on the war, were thereby saved.

In these years there was not only considerable improvement in fusion-gas welding and the plants and equipment necessary to carry it out, but also in the construction of suitably designed and satisfactory machines for arc and resistance welding.

At that time welding, using the newer processes, played its most important rôle as an accessory for repair purposes. It was soon recognized, however, that welding was sufficiently economical for manufacturing new parts, in place of fire welding and riveting.

* The term was not well chosen. In a certain sense electric arc welding is also autogenous welding. Consequently the term has now been altered, and, in accordance with a suggestion of the Technical Welding Committee of the V.D.I. (Association of German Engineers), the process is to-day termed " Fusion Gas Welding ".

The technique of fusion and resistance welding, however, experienced a remarkable development during the war, and in the last few years has extended into almost all fields of technology.

Independently of these processes, the aluminium thermit welding process was developed in the years 1894 to 1910. This is based on the property of aluminium of burning with oxygen like carbon-containing materials, thereby developing temperatures which are 1850° F. (1000° C.) higher than those produced in the furnace and which, therefore, make it highly suitable for welds of a special kind.

2. Definitions of Welding and of Welding Processes.

In view of the recent welding processes, it is now more necessary to enlarge on the definition of welding than was formerly the case. The question " What is welding?" has, therefore, been answered by a sub-committee on " Definitions and Symbols " of the Technical Welding Committee of the Association of German Engineers, as follows:

" Welding is understood to mean the joining of two metallic articles of the same or different materials by the addition of heat, in such a way that the junction zone of the members joined forms as homogeneous a whole as possible."

Definitions and Symbols of the various Welding Processes

Definitions

Welding is divided into two categories:

1. *Pressure Welding*

The joining of articles in the plastic state by the use of pressure. The following processes belong to this class:

(*a*) Forge welding (fire, water-gas).
(*b*) Electric-resistance welding (for short, R).
(*c*) Thermit welding, in so far as it results in the heating of the ends to be joined, only up to the plastic state.

2. *Fusion Welding*

The joining of articles in the fluid condition at the junction zone with or without the addition of suitable material. The following processes belong to this class:

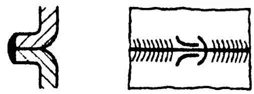
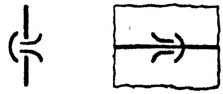
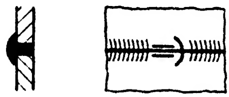
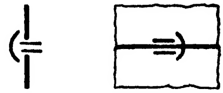
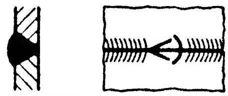
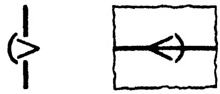
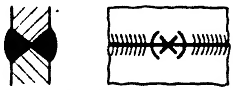
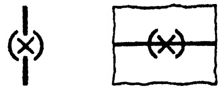
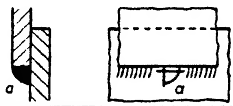
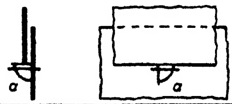
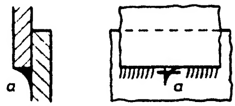
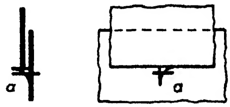
(*a*) Runner and riser casting processes.
(*b*) Arc welding (Benardos, Slavianoff, Zerener; for short, A).

(*c*) Fusion gas welding, oxygen with a gas (illuminating gas, hydrogen, acetylene, &c.), as well as with liquid fuels in the vapour state (for short, G).

(*d*) Thermit welding in so far as the heating causes the ends to be joined to become molten.

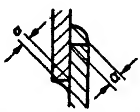
Since the designer has to indicate clearly on the drawing the welding arrangements which he uses, so that the workshop may work to them without further explanation, symbols must be used which clearly show these arrangements. It is desirable that any illustrations on drawings should be identical for all offices. In different countries, therefore, symbols for weld seams of different types have already been standardized. As an example, the symbols for fusion welding, which have been agreed upon by the German Standards Committee in D.I.N., 1912, are given in the following pages. The natural shape of the cross section is also shown by a symbol. In addition, a distinction should be made between welds which may be seen and those which cannot be seen.

Fusion Welding Weld Seams	7A Welding	Sheet 1

Title		Standard Illustration	Symbol
Flanged Seam			
Butt Seam	I Seam		
	V-Seam		
	X-Seam		
Fillet Seam	Full Fillet Seam Continuous		
	Light Fillet Seam Continuous		

On weld seams without reinforcement straight lines are drawn instead of circular arcs. e.g.

Meaning of Dimension 'a'



In addition to the thickness 'a' of the weld seam (e.g. ¼") the length of the weld seam (e.g. 8") may also be given as follows

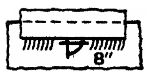


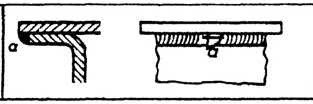
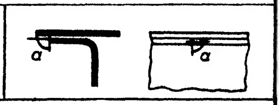
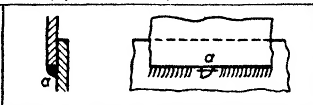
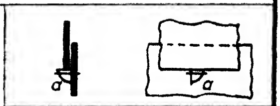
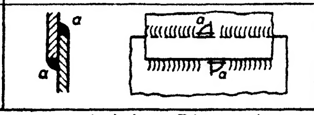
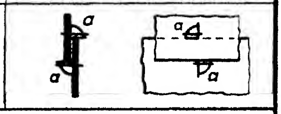
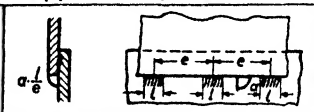
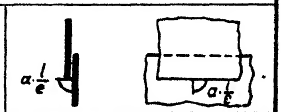
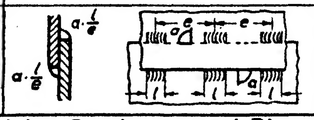
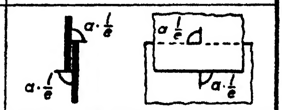
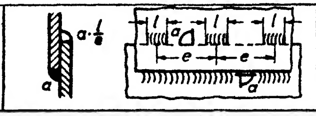
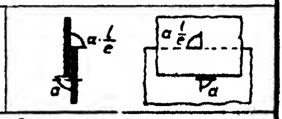
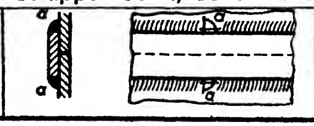
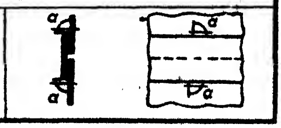
Illustration for Hidden Weld Seams

Examples of Application.
See overleaf

May 1932. Technical Committee for Welding Technology of the Association of German Engineers

Fusion Welding

Examples of Application for Fillet Seams — Welding — 7a — Sheet 1

Title	Standard Illustration	Symbol
Flanged Edge Joint		
Fillet Seam One Side		
Lapped Joint, Continuous Seam		
Fillet Seam One Side		
Fillet Seam Both Sides		
Lapped Joint, Discontinuous Seam		
Fillet Seam One Side		
Fillet Seam Both Sides		
Lapped Joint, Continuous and Discontinuous Seam		
Fillet Seam One Side		
Strapped Joint, Continuous Seam		
Fillet Seam, Continuous both Sides		

(1) Only full Fillet Seams have been illustrated. For light Fillet Seams the corresponding symbols which relate to these are to be used

Fusion Welding Weld Seams	7c Welding	Sheet 2

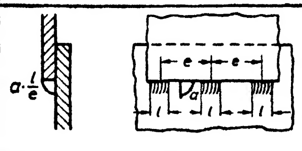
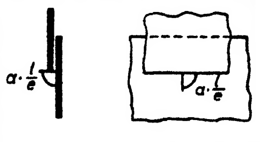
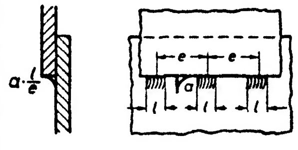
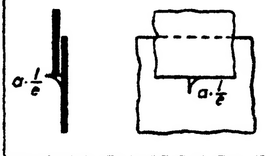
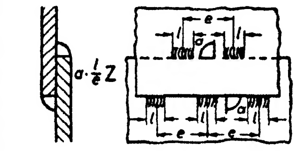
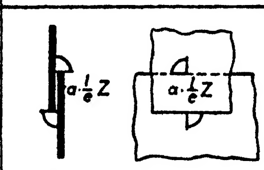
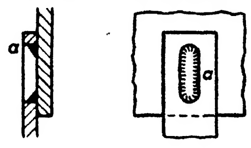
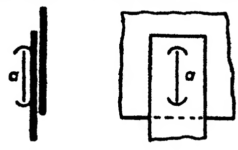
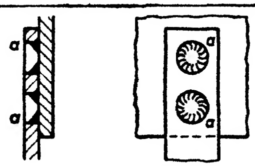
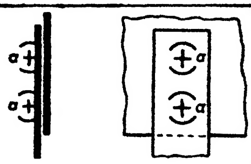
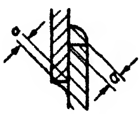
Title		Standard Illustration	Symbol
Fillet Seam	Full Fillet Seam Discontinuous		
	Light Fillet Seam Discontinuous		
	Full Fillet Seam Staggered		
Slot Seam	Elongated Hole		
	Circular Hole		

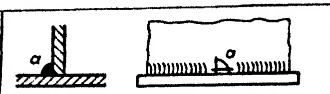
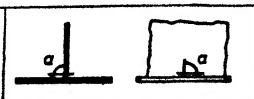
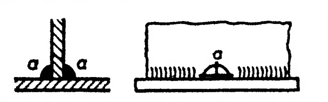
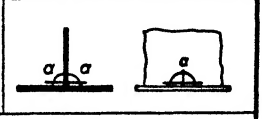
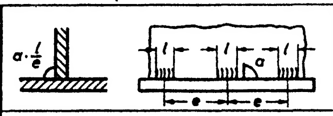
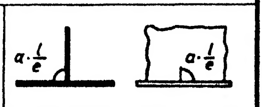
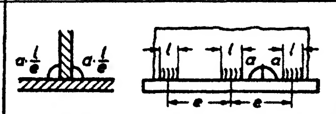
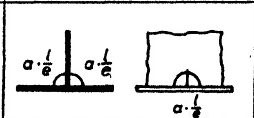
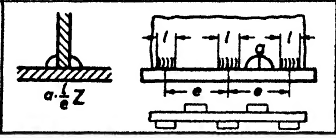
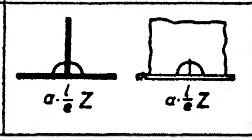
Illustration for Hidden Weld Seam 

Meaning of Dimension 'a' 

Examples of Application.
See overleaf

May 1932. Technical Committee for Welding Technology of the Association of German Engineers

Fusion Welding Examples of Application for Fillet Seams	Welding	7a Sheet 2

Title	Standard Illustration	Symbol
T Joint, Continuous Seam		
Fillet Seam One Side		
Fillet Seam Both Sides		
T Joint, Discontinuous Seam		
Fillet Seam One Side		
Fillet Seam Both Sides		
Fillet Seam Staggered		
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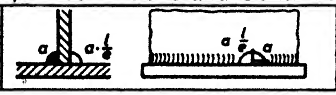
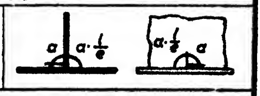
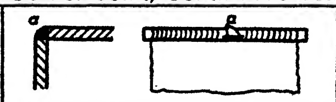
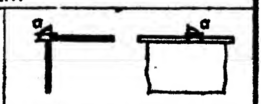
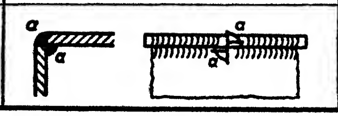
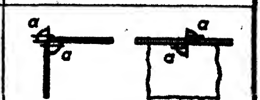
Fillet Seam Both Sides		
Corner Joint, Continuous Seam		
Fillet Seam externally		
Fillet Seam externally and internally		

(1) Only full Fillet Seams have been illustrated. For light Fillet Seams the corresponding symbols which relate to these are to be used

CHAPTER II

Fusion Welding

1. Welding Equipment for Fusion Welding.

According as the joining of the articles is to be carried out by pressure welding or fusion welding, there are various means available for producing the heat for the welding process. In addition to the smith's fire or oven, which is well known from the forge-welding process, heat which is produced by the burning of water-gas with compressed air or aluminium with iron oxide is also used in pressure welding. In addition, there is the preferable source of heat which is available from an electric current by utilizing the external resistance of a conductor or the resistance set up by bridging an air gap. In fusion welding, the heat is produced by the combustion of various gases, preferably acetylene with oxygen, or by means of an electric arc. In addition, there is also the process in which the heat is produced by burning aluminium with iron oxide.

(*a*) FUSION-GAS WELDING

Welding Gases

In fusion welding, acetylene is preferably used as a combustible gas and to a lesser extent hydrogen, coal gas (illuminating gas) mixed with compressed air or acetylene, methane mixed with hydrogen or acetylene, as well as benzol or benzol vapour all of which are burned with oxygen. Blaugas has not proved suitable for welding.

Oxygen (O) is the element which is most largely distributed on our planet. It is contained in the solid earth crust, in water, and in air.

Oxygen is obtained, either by the electrolysis of water, or chiefly by separation in the liquid state, from atmospheric air at low temperatures. The oxygen thus obtained is compressed in steel cylinders

to 150 atmospheres pressure and put on the market. In this condition, it always contains impurities to some extent, chiefly nitrogen. The degree of purity amounts from 96 to 99·5 per cent.* These impurities have no influence on the welding process so long as they do not exceed 2 per cent, but they have a considerably harmful effect on the efficiency of the flame for cutting with acetylene or hydrogen. A high percentage of oxygen is the most economical for this purpose.

It has also been noted that the oxygen supplied in cylinders often has a high water content. Consequently, not only is the weight of the filling affected, but during the process of combustion the temperature is reduced. Moreover, such cylinders suffer from rusting. Therefore it is advisable to take care that oxygen is supplied in the driest possible state.

By means of a new process which is closely connected with the name of Dr. Heylandt, it is also possible to obtain oxygen in the liquid state.

Considerable savings in transport and storage are, therefore, made possible. In order to make the liquid oxygen suitable for welding purposes it is transformed into the gaseous state in so-called gasifiers.

Hence the dangers which previously existed in the transport of oxygen in steel cylinders have been considerably reduced, and in some respects entirely eliminated.

Acetylene (C_2H_2).—Acetylene is the most widely used gas in fusion welding because, compared with other gases, it possesses two advantages which make it especially suitable. These are the high temperature of its flame which is not equalled by any other combustible gas and which amounts to 5600° F. (3100° C.), depending on its mixing ratio with oxygen, and secondly, the reducing action of its flame, which prevents the formation of oxide inclusions which impair the weld.

Acetylene gas is a chemical compound of two parts of hydrogen and two parts of carbon. It is produced from calcium carbide and water.

Calcium carbide (CaC_2), called carbide for short, is a compound of calcium and carbon. It is a crystalline product of dark grey colour, frequently occurring with ferro-silicon as an impurity. Carbide combines with water, producing gaseous acetylene, and calcium

* Rimarski, Kantner and Streb, " Influence of Oxygen Purity on cutting with Oxygen and Acetylene ", *Autogene Metallbearbeitung*, Vol. 21 (1928), p. 3.

hydroxide is left behind as the remaining product. In consequence, it must be rendered completely dry before it is used, and protected against dampness of any kind, including vapour from the air. It is commercially handled in tightly closed shaped drums of 220 lb. capacity, and in various gradings. Care must be taken, in storage, to see that the drums do not stand in a damp place, since the dampness might penetrate into a damaged drum and cause the generation of gas and explosions. In addition, the drums must not be opened with a flame or soldering iron because of the danger of an explosion. The removal of the lid with tools which might cause a spark, such as a chisel or caulking tool, may be dangerous.

One pound of calcium carbide and ·56 lb. of water yield 1·16 lb. of lime and ·4 lb. or 5·5 c. ft. of acetylene, giving out 1782 B.Th.U.s. In practice, this theoretical gas yield is not attained, since commercial carbide is not chemically pure, and the generation of gas in practical acetylene installations is not complete. For practical purposes, one may reckon on a gas yield of 5 c. ft. from 1 lb. of carbide with a grading of 15–18 mm. at 60° F. (15° C.) and 30 in. barometric pressure, and on 4·5 c. ft., where the grading of the carbide is from 4 to 15 mm., margin of error 2 per cent.

Finely ground calcium carbide has been put on the market under the name of "*Beagid*" or "*Karbidid*". This is wrapped with a binding material and pressed into cylindrical vessels of about 3 in. diameter and 4 in. long. It has the property that, when in contact with water, it disintegrates more slowly than coarse carbide and this slows up the generation of acetylene which does not occur so violently as with carbide, so that when a low take of gas occurs, there is no excess gas obtained. It is also possible to interrupt the gas take for long periods without setting up losses of gas.

The price of the gas produced with "Beagid" is almost the same as that which has to be reckoned with in small acetylene generators.

The generation of acetylene from calcium carbide or "Beagid" takes place in specially built generators which will be fully described in succeeding pages. As a rule, acetylene is generated at the place where it is to be used, but it is often taken from cylinders in which it has been compressed at high pressure.

These acetylene cylinders are subject to special regulations, which are necessary because of the danger from acetylene standing under high pressure. Acetylene itself, as long as it is not mixed with oxygen or air, is not dangerous. Mixtures of gas and air, however, are explosive when there is more than 2·8 per cent or

less than 73 per cent of acetylene in the mixture. For mixtures of oxygen and acetylene the limits are still wider apart. At the same time, even if there is no mixture of air or oxygen, there is still the danger of the decomposition of acetylene by heat or shock if acetylene is brought up to a high pressure. According to Rimarski, the limit of decomposition is about 1·6 atmospheres (23·5 lb./in.^{2}). Consequently acetylene cannot just be compressed to a high pressure and put into service in cylinders, but it must conform to special regulations which eliminate the explosive decomposition of the gas in all circumstances, even when ignited.

For this purpose the cylinders are filled with a porous filler mass saturated with acetone. Acetone, like many other liquids, has the property of dissolving gaseous acetylene. The solvent property of acetone is specially high and amounts to 23 c. ft. of acetylene to 1 c. ft. of acetone at one atmosphere (14·7 lb./in.^{2}). The acetone must be chemically pure and must contain no free acetic acid and no water. Traces of hydrogen sulphide and hydrogen phosphide must be avoided. For dissolving acetylene the cylinders, which usually have a capacity of 40 litres (1·4 c. ft.), are filled to $\frac{4}{10}$ of their capacity with acetone. The filler mass has the property of immediately damping down any explosion which is set up by heating, shock or ignition, and preventing its development. Consequently the filler mass must so fill the space in the bottle that there are no cavities in which the dissolved acetylene can collect in the gaseous state. Further, it must not settle in service owing to bumps, and it must not leave the cylinder walls.

In order, therefore, that filler masses should afford absolute protection, they are governed by strict legal regulations. They may only be put on the market after a series of chemical and physical tests which are carried out in the Chemisch-Technische Reichsanstalt (Chemico-Technical State Laboratory). Filler masses are classified as loose, compressed, and solid, and usually consist of materials such as wood charcoal, granular cork, asbestos, or diatomaceous earth. Filler masses may only reduce the capacity of the cylinder by 25 per cent at the most.

In this way it is possible to bring acetylene on to the market in steel cylinders at a pressure of 15 atmospheres (220 lb./in.^{2}).

Hydrogen (H).—This is an element which, like oxygen, is present on the earth in large quantities and appears in a multitude of compounds.

Hydrogen is obtained either like oxygen by the electrolytic

method from acidulated water or sodium lye, or by means of the so-called contact process in which water vapour is led over heated iron. Its production requires large quantities of energy.

Commercially, hydrogen is obtained like oxygen in steel cylinders compressed to 150 atmospheres.

By mixing oxygen and hydrogen in a torch a point flame is obtained at a temperature of about 4350° F. (2400° C.).

Hydrogen was the first gas used in welding in industry. Later it was replaced by acetylene, which proved to be more economical, on account of its higher temperature, so that to-day hydrogen is only used for the welding of very thin steel sheets and easily melted metals, especially aluminium, for which it has advantages in certain cases.

Methane (CH_4).—In order to utilize gas from coke ovens, attempts have been made to weld with methane, a light hydrocarbon, which has less tendency to explode than acetylene. The limits of decomposition lie between 5 and 10 per cent of methane in an air mixture. Although methane has a very high calorific value, it is unsuitable for welding as a pure gas, as it has a combustion temperature of only 3280° F. (1800° C.) and possesses a combustion velocity of one-tenth that of hydrogen. Since this velocity, along with the quantity of the gas and the magnitude of its calorific value, controls the temperature of the flame, methane is mixed with other gases which have a high combustion velocity, and also a high combustion temperature. Commercially two mixtures of this type are sold under the name "Methane L" and "Methane B". Methane L is a mixture with hydrogen and has a combustion temperature of 3630° F. (2000° C.). It is suitable for cutting and lead burning and for the welding of thin aluminium.

Methane B is a mixture with acetylene and has a flame temperature of 4890° F. (2700° C.). Compared with pure acetylene Methane B is not very important for welding.

Bituminous Coal Gas.—Bituminous coal gas is obtained from the distillation of coal. Its distribution as illuminating gas makes it very cheap. It contains as combustible gases hydrogen, methane, carbon monoxide, and heavy hydrocarbons. On account of its low combustion velocity it is always mixed, either with compressed air or acetylene. As long as illuminating gas is used for cutting thin plates it gives a clean cut.

Benzine and Benzol Vapour.—Benzine and Benzol contain in general liquid hydrocarbons which are vaporized in a special

heating device and used for welding and cutting by combusting them with oxygen. The vapours have almost the same flame temperature as hydrogen and methane. Benzine and benzol vapours are very unsuitable for welding thick plates, but are suitable for welding thin plates and for cutting. As with illuminating gas, very clean cut edges can be obtained. Because of the ease with which the equipment may be handled and the cheapness of the fuel, they are very well suited for general practical work. It must be borne in mind, however, that hydrocarbons freeze at temperatures not particularly low, so that their use in the open or in winter is difficult and wasteful of time.

2. Welding Apparatus, Welding Equipment, and their Accessories.

Welding plants and welding equipments are the decisive factors in the success of welding. No one type of these is suitable for all purposes. The standard of quality required in the weld seam, as well as the cheapness of the work, demands an accurate choice of the numerous good and excellent plants and equipments which may be found on the market. Consequently a thorough knowledge of these items is indispensable. We begin with a fairly detailed survey of the equipment for fusion-gas welding.

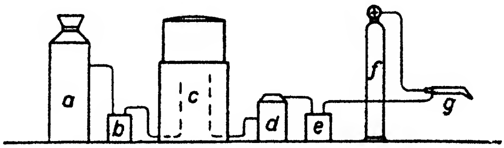


Fig. 1.—Lay-out of an acetylene welding plant

a, Acetylene generator; *b*, washer; *c*, gas-holder; *d*, purifier; *e*, main hydraulic valve; *f*, steel cylinder for oxygen; *g*, torch.

It has already been mentioned that various gases and liquids may be used as fuels in fusion-gas welding. For all welding processes of this type, the production of the welding flame necessitates the use of oxygen, which must always be available, compressed in steel cylinders, in the plant concerned.

The source of gas and the accessories vary with the kind of gas which is used. Fig. 1 shows an acetylene plant in which the source of gas is an acetylene generator *a*. The necessary equipment consists of a gas-holder *c*, which is connected by means of a pipe line to the washer *b*. The acetylene gas which collects in the container passes through the pipe line, by way of the purifier *d*, and

into the main hydraulic valve *e*, to the stop valve, from which it is led to the torch *g*, in conjunction with a further hydraulic valve. The oxygen is led to the torch through a second flex, through a reducing valve on the cylinder *f*.

The installation is much simpler when dissolved acetylene, hydrogen or methane is used. In this case, in addition to the oxygen cylinder *b* in fig. 2, only a second cylinder *a*, which contains one of these gases, is necessary. Both cylinders are provided with reducing valves through which the gases are led to the torch *c*.

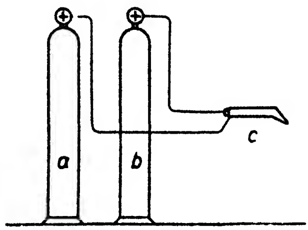


Fig. 2.—Lay-out of a welding plant using gas from cylinders

a, Steel cylinder for acetylene, hydrogen or methane; *b*, steel cylinder for oxygen; *c*, torch.

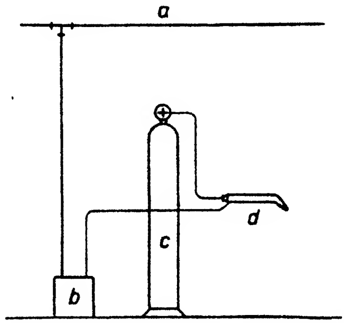


Fig. 3.—Lay-out of an illuminating gas welding plant

a, Illuminating gas; *b*, hydraulic valve; *c*, oxygen cylinder; *d*, torch.

Fig. 3 shows the illuminating gas welding plant. The gas supply is the illuminating gas pipe *a*. Hydraulic valve *b* is also necessary as part of the equipment, and this is coupled in between the gas supply and the torch *d*. The oxygen supply is, as before, from cylinder *c*.

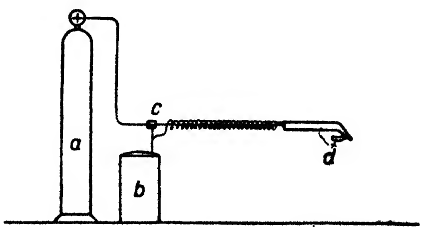


Fig. 4.—Lay-out of a benzol welding plant

a, Oxygen cylinder; *b*, container for liquid fuel; *c*, distributing piece; *d*, torch.

Finally fig. 4 shows a benzol welding outfit. The cylinder *a* supplies the oxygen which is then conducted through a pipe to a distributing piece *c*, belonging to the container *b*, and then through a further pipe to the torch *d*. The vessel *b* contains the liquid fuel which is compressed into the fuel passage of the torch *d*, through a spirally wound brass pipe surrounding the pipe feeding the oxygen.

Acetylene Generators.—Acetylene generators may be divided into separate groups according to various classifications, viz. the

size, the apparatus for which they are to be used, the pressure under which they work, and the type of construction. As regards size, generators are divided into (*a*) portable apparatus up to a carbide capacity of 4½ lb., which may be used for temporary work in any buildings (M apparatus); (*b*) semi-portable generators up to 22 lb. carbide capacity and up to 225 c. ft./hour output, which are permitted in workshops under special regulations (J apparatus); (*c*) large generators of more than 22 lb. carbide capacity which may only be erected in special generator rooms and in the open air (S apparatus). The use of the apparatus is also covered by regulations.

M apparatus is suitable for soldering work and illuminating purposes. The question of its use for welding does not arise.

J apparatus will be used anywhere where the amount of work is not very large or where welding is only carried out intermittently, since the output of this apparatus is, in accordance with its size, only small. Difficulties may easily be met if the generator has only one small filling device, as is the case with the majority of small J apparatus. There is then the disadvantage, when a large amount of welding work is being carried out, that the welding has to be interrupted in order to add carbide if one filling is insufficient. Through these interruptions, not only is the welding work delayed, but the quality of the weld is impaired. In recent years J apparatus has, therefore, been constructed with two filling and generating devices, so that one can always be filled up while the other is in use.

A further disadvantage of many types of J apparatus is that it does not supply as pure and cool a gas as a permanent large generator and, therefore, it is less suitable for high quality welding. The chief blame is to be put on the washer, the importance of which will be discussed later, as this cannot be made large enough without destroying the portability of the equipment or reducing the pressure considerably.

On the other hand, J apparatus, especially of the smaller types, has an advantage which should not be underestimated, namely, that it can be built with all the fittings and oxygen cylinders on a light wagon, and thus made capable of being transported with ease to any spot where welding is to be carried out.

However, as cylinders of dissolved acetylene afford the same advantage of portability and supply a very cool gas, they compete seriously with the J generator, and perhaps might have eliminated it altogether, had not dissolved gas been much more expensive.

Where the quantity of work justifies the installation so that a

large generating plant can be economically employed, the stationary large generator will be chosen as the most suitable, since any number of welding stations may be coupled in to it, according to its size. Admittedly special lines leading to the various welding stations are of course required, and may make the installation very expensive if the stations are wide apart. Since, however, the price per cubic foot of acetylene from a large generator is about $\frac{1}{2}d.$, compared with about $\frac{3}{4}d.$ for J apparatus and about 1*d.* to $1\frac{1}{4}d.$ for dissolved gas in hired cylinders, the costs which are set up in permanent installations may easily be written off. Large permanent generators have, in any case, the advantage, compared with J apparatus, that they supply a very much purer and cooler gas. As compared with dissolved acetylene, the considerable difference in price of acetylene is in their favour. The general arrangement of a permanent welding plant remains to be considered. Large permanent generators are constructed for a carbide capacity of ·2 to 1·0 tons. Various sizes are also available, according to the work to be done. It should be specially noted that it is inadvisable to select a plant which is too small, quite apart from any reference to the increase of requirements at some later date which usually occurs owing to increase in the welding work. For, besides this consideration of expanding requirements, it must be remembered that reliable experiments have shown that generators, on continuous work, do not reach the maximum hourly output which is given on the information plate. As a rule they only reach about 40 to 60 per cent of this, and in many cases only 30 per cent. When choosing the size of a generator, the maximum output should not be ignored, but it should also be ascertained whether the generator gives the required gas quantity on continuous work.

It is particularly convenient to connect a permanent acetylene welding plant of this kind with a plant for a central supply of oxygen. In the central oxygen station there are two batteries, consisting of a row of steel cylinders with main stop valves. The number of cylinders depends on the load of the welding plant. One of the two batteries is in commission, the other is provided with full cylinders and serves as a reserve to be coupled in when the first battery is used up. During the working of the second battery the first is replaced by full cylinders. The coupling piece on the individual cylinders with the main supply pipe, which supplies oxygen through smaller pipes to the working points, is fitted with a flexible screwed socket or pipe screwed at both ends and made of copper.

In addition to providing uninterrupted working, a central oxygen plant offers further advantages. The transport costs which are entailed for each cylinder are saved, and at the same time working is much safer. In addition, the content of the cylinder is more completely used up, since the cylinders may be emptied to two or three atmospheres, whereas, with single cylinders, considerable quantities are often left over, though perhaps not sufficient for a piece of welding work.

If the distributing system is not worked at the full pressure of the cylinders, but at an intermediate pressure of 20 atmospheres (294 lb./in.^{2}), which is preferable, a perfectly constant working pressure may be attained as the pressure reduction takes place in two stages and the danger of burning the pressure reducing valves is thereby lessened. Moreover the pipe-line system is cheaper and it is easier to keep it tight.

We distinguish between two types of generator, *Low-pressure Generators* and *High-pressure Generators*. In the former the gas pressure goes up to ·03 atmospheres (12 ins. of water) and in the latter up to 1·5 (22·0 lb./in^2) atmospheres and more.

For a long time only low-pressure generators were built, because it was known that acetylene gas would decompose explosively even at low pressure. After it had been established by Rimarski that the decomposition limit lay above 1·5 atmospheres, the building of generators for higher pressures, up to 1·5 atmospheres, as stated above, was permitted by German regulations. Low-pressure and high-pressure generators are in essence alike. The following point, however, is to be noted. As will be shown later, if uninterrupted working of the welding torch is to be obtained, a pressure excess of 2–4 in. of water must be present. Low-pressure generators certainly give this pressure, but a large proportion of the pressure is dropped in hydraulic valves and pipe lines, especially when these extend for large distances and, as can frequently be observed, they are not well planned but built with sharp bends in which water pockets can form. In these circumstances it may so happen, because of the injector effect in the torch, that a vacuum is set up in the pipe line. Moreover, even when there is a high pressure in the torch the welder is often compelled to weld with excess oxygen which, as will be shown later, can seriously impair good welding work.

In such cases the high-pressure generator is to be preferred. With such a generator the gas may be laid over long distances without

there being any fear that insufficient pressure will be available at the torch. In addition, there is the advantage in using high-pressure generators that the diameter of the lines may be made smaller than with low pressure and consequently considerable savings in cost may be made in the pipe-line system. If a low-pressure plant exists, however, steps may be taken to couple acetylene compressors or blowers into the line. Various designs for these have been put on the market. It is therefore unnecessary to replace the existing low-pressure plant with a high-pressure plant if it is desired to extend the pipe-line system to a greater extent than low-pressure plant will permit. Where new plants with extensive pipe-line systems are considered, it would be preferable initially to select the high-pressure generator. There is, however, no need to go right up to the limit of 1·5 atmospheres (22 lb./in.^{2}) as, in general, it is sufficient to work with pressure of ·3 to ·6 atmospheres (4·5–9 lb./in.^{2}), according to the local conditions. It is very seldom that a higher working pressure is necessary. Acetylene generators are divided into three groups, according to the method of working:

(*a*) Generators on the " carbide to water " system. Carbide is fed in and brought into contact with the water.
(*b*) Generators on the " water to carbide " system. The carbide is stationary and the water flows on to it.
(*c*) Generators on the displacement (recession) or immersion system.

In group (*c*), the carbide and the water are alternately brought into contact with one another and separated.

For each of these groups there is a definite simple basic form, from which a large number of constructed types have been built and are commercially available. Along with these may be found a series of intermediate types which cannot definitely be placed in any of these groups.

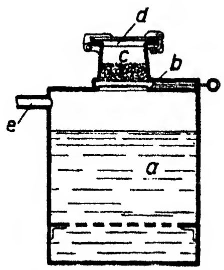


Fig. 5.—Basic form of the " carbide to water " system
a, Water chamber; *b*, slide valve; *c*, carbide container; *d*, cover; *e*, pipe going to gasholder. To produce acetylene the carbide is put into the water.

Fig. 5 shows the basic form of the carbide to water system. The carbide container *c* is placed above the water chamber *a*, separated from it by means of a slide valve *b*, and closed above by means of a tight fitting cover *d*. If the slide valve *b* is withdrawn the carbide falls into the water and acetylene is generated and flows through

the pipe *e* into the gas holder and thence to the points where it is used. The slide valve *b* is then shut and the container filled once more. In the lower portion of the water space a grid is built in through which the sludge which is formed falls to the ground, from which it may be removed from time to time. In addition care must be taken to renew the water in the generator regularly.

The basic form of the water to carbide system is shown in fig. 6. The water for the generator is brought down from a special vessel *a*, separated from the generator space *b*. The carbide is brought in a suitably shallow container *d*, through the opening *c*, which may be shut and made gas-tight. When the cock *e* is open a certain

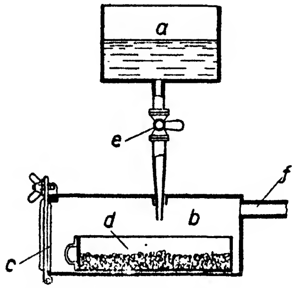


Fig. 6.—Basic form of the " water to carbide " system

a, Water chamber; *b*, generator space; *c*, outlet which may be closed; *d*, carbide container; *e*, stop cock; *f*, pipe going to gas-holder. To produce acetylene, the water flows on the carbide.

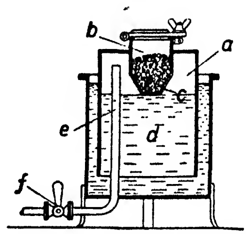


Fig. 7.—Basic form of the " displacement or immersion " system

a, Gas-holder bell; *b*, carbide container; *c*, perforated bottom on *b*; *d*, sealing water; *e*, pipe line to point of consumption; *f*, stop cock. To produce acetylene carbide and water are alternately brought into contact and separated from one another.

quantity of water runs on to the carbide and acetylene is generated and may be led away through the pipe *f*. If the cock is shut the generation of the gas ceases as soon as the quantity of water which has got into the generating space has been used up. The process is repeated by opening the cock again until all the carbide has been decomposed.

Finally fig. 7 shows the basic form of the displacement or immersion system. The gas-holder bell *a* forms the generating space, to the cover of which there is attached a carbide container *b*, provided with a perforated bottom *c*. The gas container *a* may be connected directly to the main gas holder, or arranged to float inside it. As soon as the container is filled with carbide and dipped into the water, acetylene is generated and, when the cock *f* is opened, flows through the pipe line *e* to the place where it is used. If the gas consumption is interrupted, however, the gas which has been

generated collects in the gas bell *a* and raises the bell, provided it is arranged to float, in the way shown in the figure, so that the container rises above the water (immersion system), or displaces the water in the main gas holder if it is connected directly to it (displacement system). In both cases the gas which is generated breaks the contact of the water with the carbide so that the generation of gas is interrupted. As soon as the gas has been used up and the gas holder is empty, the bell falls or the water rises again in it, until the water and the carbide are again in contact and the generation process is repeated. The displacement system is the commoner.

In a generator working on the displacement system, the carbide remains stationary, as in group *b* (p. 19), and the water flows to it; and in a generator working on the immersion system the carbide is fed into the water as in group *a*. Hence the displacement and immersion systems have been absorbed in these groups *b* and *a*, and only two groups are distinguished from one another. As a matter of fact displacement and immersion equipment are similar in their method of working, whereas they are entirely different from those in groups *a* and *b*. For this reason the division into three groups has been retained in this book.

Each of the types mentioned has certain advantages and also definite disadvantages which may usually be overcome by taking suitable precautions. The points involved will now be briefly explained.

Generators working on the carbide to water system have a very important advantage compared with the others, in that the carbide comes into contact with a large quantity of water by which perfect gasification and a high yield of gas is obtained; moreover, the gas generated is well washed and cool. Its disadvantage is that it can give rise to explosions, unless special precautions are taken. From the gas which is generated, and the air which is present in the generator, a mixture of gas and air is formed in every generator when it is first put into service. Such mixtures are highly explosive if, as has been previously mentioned, there is more than 2·8 per cent and less than 73 per cent of acetylene. This explosive mixture is allowed to escape before the apparatus is put into service as it is relatively unsuitable for welding, but gas mixtures of this kind stay behind in small pockets, connecting pipes and damaged places. If there is any possibility that these mixtures may be ignited then there is a risk of explosion. Experience has shown that there is a certain danger in such carbide to water systems, as the generator

must be opened during charging and sludging, and the entry of fresh quantities of air is therefore possible. Ignition of the explosive mixture may occur through pieces of carbide introducing impurities such as ferro-silicon, which are often present in carbide but may quite easily be removed by means of magnets. If these particles of metal strike iron on the generator or the charging hopper during filling, sparks may occur. Attempts have therefore been made to cover the charging hopper with zinc sheet, but without success, as this covering is very soon damaged. Explosions have also been traced to carbide dust becoming incandescent. Carbide dust when mixed with water clings together so as to form lumps, and gradually heats up to red heat, as may be confirmed by carrying out a test in a tumbler. The danger of explosion may, however, be averted by removing the pieces of ferro-silicon from the carbide which is being put in, and by leaving the dust behind. It usually happens, however, whether to save trouble or in ignorance of the danger, that the drums of carbide are tipped into the charging hopper as they come from the store along with the accompanying ferro-silicon and dust.

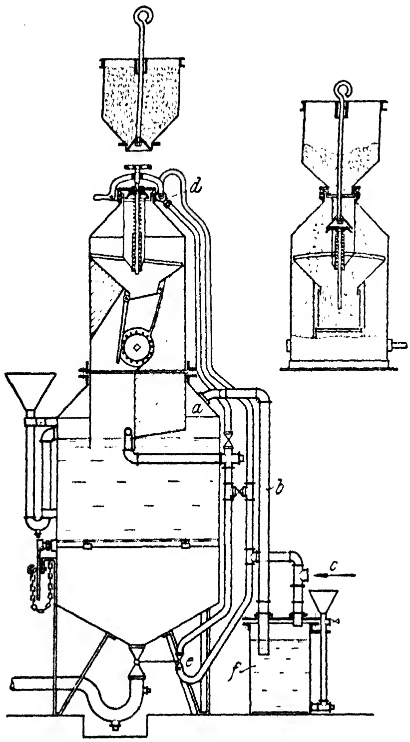
This danger may be met, at all events with large plants of this type, by adopting special precautions. One method is to provide a primary charging hopper at the inlet, which prevents the ingress of air during the charging of the generator. Careful tests have shown that by this means explosive mixtures in the generator can definitely be avoided, even though small and harmless quantities of air may be present in the primary charging hopper in certain circumstances and may get into the generator. The primary charging hopper, therefore, fulfils its purpose, at least during uninterrupted running. Mixtures of gas and air which remain in the generator when it is put into commission, or which may be formed by the entry of air during sludging, must be prevented in another way. For this purpose both the charging inlet and the sludging outlet are connected to the gas-holder, so that the gas which is under pressure in the holder immediately flows into the generator as soon as the pipe is opened either for filling or sludging. In this way the ingress of air under atmospheric pressure is prevented. The same device may also be used to blow out the generator with acetylene gas when it is put into commission, and thereby drive out the mixture of gas and air which is present at the start. To prevent this mixture from remaining in odd corners, new generators are so built that all dead space is avoided. Old generators may be suitably lined for this purpose.

With apparatus so equipped there is no danger whatsoever. As a rule it is not possible to use safety precautions with J equipment. It has been observed, however, that sparks from falling carbide only occur if the height of drop is over one metre (3 ft. 3 in.). This drop is not reached with J equipment. Consequently the Acetylene Association has sanctioned the continued use of such equipment with few exceptions. All the same, the carbide to water plants have lost some ground to the other types of construction because they cannot be built as high-pressure systems, in which it is not permissible for the purpose of filling or sludging, to open up the generator vessel, which is under pressure.

Generators built on the water to carbide system are less dangerous. Only by gross disregard of regulations governing their operation, can an ignition occur in the generator space. At the same time, compared with generators working on the carbide to water system they have the disadvantage that the quantity of water which is available for generating gas is considerably less and consequently the gas is not sufficiently cooled. This disadvantage may be avoided by spraying the gas retort with water and sending the gas through a specially large washer, which may be dispensed with in the carbide to water plant. The gas is not only purified in this but also cooled. There is, however, the danger that the carbide in the container may not get sufficient water if the container is filled too full. The carbide sludge which is formed during generation fills the container, so that only a small quantity of water can come in contact with the particles of carbide. These then heat up and decompose with the generation of large quantities of heat, causing some danger or, at the very least, considerable diminution in quality of the gas. This decomposition, which is termed polymerization, causes the gas to heat up considerably and consequently there is a tendency for it to take over considerable quantities of water vapour. On this account the acetylene code prescribes that the container shall only be half full. In addition copious quantities of water are necessary. With such precautions these plants work quite satisfactorily in every way.

In displacement equipment, as in carbide to water generators, there is an adequate quantity of water. There is, however, the danger of after-make. The generating process is not interrupted immediately after breaking contact between the water and the carbide. The moist carbide continues to gasify for some time. Because of the small quantity of water which is available, a hot gas

is generated. With long interruptions, the after-make is so excessive that the generator space is insufficient for the quantity of gas produced. It must, therefore, be made possible for the gas to escape to the open air. In this way we have on the one hand loss of gas, on the other the danger that the gas may ignite in the workshop and cause a fire.



Figs. 8 and 9.—Low-pressure generator working on the "carbide to water" system

a, Gas off-take point in generator vessel; *b*, gas pipe; *c*, outlet to gas holder; *d* and *e*, cocks; *f*, sealing water.

In order to give a better idea of the mode of operation of the three types of construction than can be obtained from studying the general basic forms, a typical and suitable practical example of each kind will be discussed in the following pages. These are chosen from a large number of serviceable and excellent generators which are on the market, but there is no intention of conveying the impression that those that have been selected take precedence over other makes.

Figs. 8 and 9 show a low-pressure generator of a rather old type working on the carbide to water system. It is fully equipped with the safety devices which have previously been described.

The method of working may be easily understood. The carbide is filled into the primary charging hopper which is not shown in fig. 8 on the closed generator, but may be seen in fig. 9, where it is shown in position on the open container turned through 90°. From this it falls on the distributing drum which is controlled by the gas-holder. This controls the consumption automatically and allows the particles to fall into water in the generator. Here it builds up on a perforated grid until it is completely gasified. The sludge collects in the lower portion of the generator below the grid. The gas is taken out from *a* and

passes through the pipe *b* through the catchpot *f* and through *e* to the gas-holder.

Safety precautions are taken in the following way. The figures show the primary charging hopper which prevents the ingress of air during the charging of the generator, and also the lining which avoids dangerous cavities. The cocks *d* and *e*, which are automatically

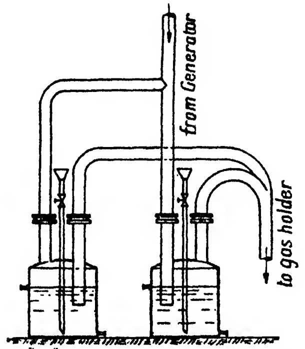


Fig. 10.—Double water-sealing vessel

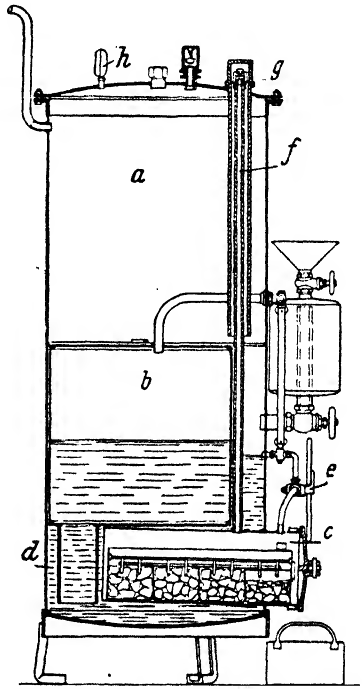


Fig. 11.—High-pressure generator—" water to carbide " system (and sliding-tray system)

a, Main container; *b*, back-pressure container; *c*, retort; *d*, cooling water; *e*, lever for feeding water on the sliding trays; *f*, uptake pipe; *g*, non-return valve; *h*, manometer.

connected with the pipe line when the generator is opened, provide additional safeguards against air getting into the generator during filling and sludging. Acetylene gas passes from the gas-holder into the generator, as the latter is now at a lower pressure and, in this way, ingress of air is prevented.

Newer generators of this type are initially so constructed that dangerous cavities are avoided, and a primary charging hopper is provided. The supply of gas from the gas-holder to the generator during charging and sludging is achieved in a simple way by fitting two catchpots which work in opposition to one another in such a way that the second allows the gas to come back by means of a reverse arrangement of the outlet pipe, as may be seen from fig. 10. This occurs as soon as the pressure in the generator starts to fall due to the opening of the valves.

Fig. 11 shows an example of a high-pressure generator working

on the water to carbide system. This is a so-called sliding-tray apparatus. It consists of the main container *a*, the back pressure container *b*, and the retort *c*, which is surrounded by cooling water *d*. By working the lever *e* water is fed into the first container chamber and the generation starts. The gas flows through the uptake pipe *f* through the non-return valve *g* to the main vessel. The gas which collects here forces back the water in the main vessel *a* into the back pressure container *b* so that if the working pressure is exceeded, the water level sinks to such an extent that the flow of water to the retort, which passes through the pipe near the lever *e*, is interrupted and generation ceases. The generation process is therefore accurately controlled in accordance with the consumption of gas. A manometer *h* shows the pressure. The container in the retort is divided into separate compartments over which water flows, one after the other.

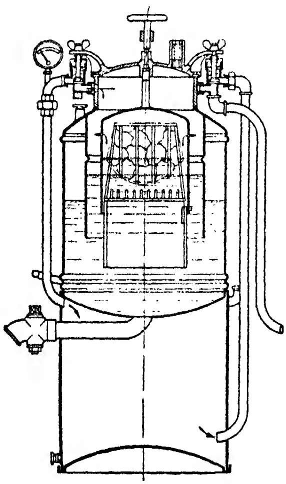


Fig. 12.—High-pressure generator —displacement system

Finally, fig. 12 shows a high-pressure generator working on the displacement system. The method of working may be seen from the figure. The carbide container, which is fitted with sludge prongs, is placed in the generator, so that the gas collector is automatically closed when the cover plate is opened. Generation starts immediately. The gas, which is collected in the gas container, displaces the water in the main container so that when the working pressure is reached, contact with the carbide ceases and the generation is interrupted. When gas is used, the water rises once more in the generator space and generation starts once again. A safety valve permits the gas to escape into the open air, if the pressure rises too high on account of after-make.

Generators are frequently constructed in pairs so that two gas chambers feed one collecting chamber and thereby uninterrupted working is made possible. One chamber can generate gas while the other is being filled with carbide. For temporary high gas takes, both generators may be used simultaneously and the output of the apparatus thereby doubled.

Recently some firms have made quite new departures which may have an influence on the construction of apparatus. They will,

therefore, be briefly mentioned here. Fig. 13 shows the inside fittings, fig. 14 the outside appearance, of a new generator working on the carbide to water system. The carbide is put into containers which are kept in a vertical position by means of catches and prevent the access of the water to the carbide. A chain drive, which is operated by the bell, releases one catch after the other, according to the gas requirement. In this way the containers are tipped into the horizontal position. The water now has access to the carbide and the generation of gas starts. The stream of gas in the generator results in a violent spraying effect and in complete gasification of the carbide. A pure and cool gas is obtained, without the danger of ignition through a spark or incandescent carbide.

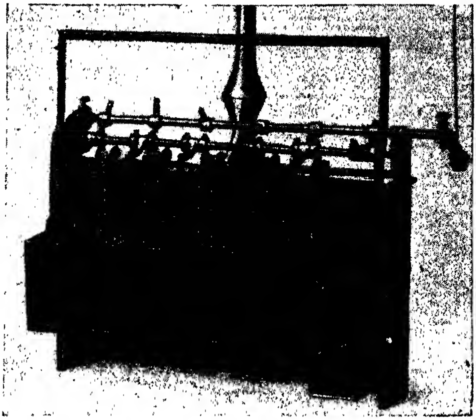


Fig. 13.—Vertical chamber generator—inside view

Fig. 15 shows a generator in which pure carbide dust or a mixture of dust and fine granulated carbide can be gasified. With this apparatus it becomes for the first time possible to make use of the waste material formed in the production of carbide, which was previously valueless. The carbide dust is stored in a container *a* and is forced into the hopper by means of a conveyor screw *b*. At the same time, a fine spray of water passes through the ring-shaped spray *c* into the chute, thus preventing the solidification of the

Fig. 14.—Vertical chamber generator—outside view

dust. By means of a stirrer the water and the carbide are carried downwards and kept continually in motion so that the water and the carbide are in intimate contact and complete gasification results.

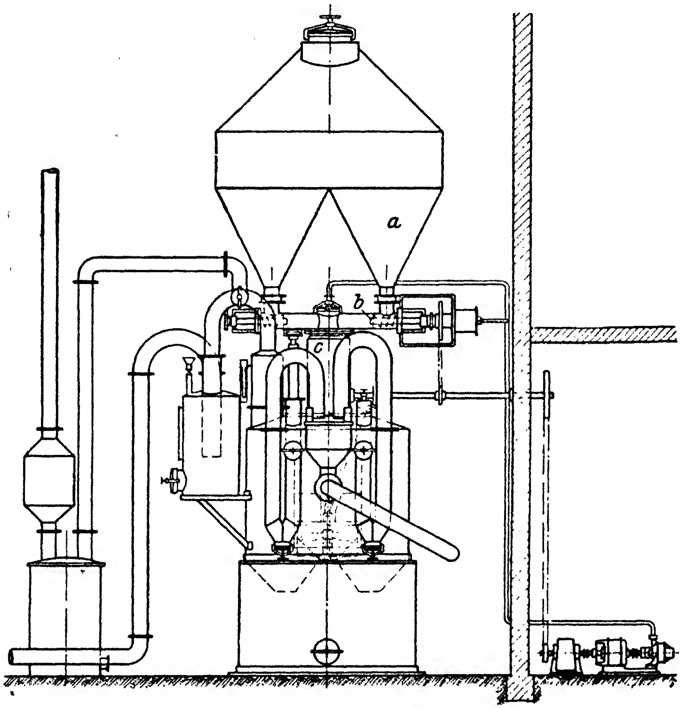


Fig. 15.—Carbide-dust generator

a, Container for fine-grade carbide; *b*, conveyor feed screw; *c*, ring-shaped spray

Fig. 16 shows another large generator of modern construction using circulating water, known as a "*Spray*" generator. The generator consists of (1) a main generator partly filled with water on which is placed a cylindrical carbide container, the lower portion of which is made into a perforated basket; (2) a carbide sluice for filling new carbide into the carbide container; and (3) a removable primary hopper which also serves the purpose of a filler hopper. At the side of the main vessel there is a centrifugal pump which is driven by a motor, and which takes water from the lower portion of the main vessel and delivers it to a spray nozzle on the inside of the container so that the water impinges with high velocity on the carbide in the perforated vessel. On account of the excess water stream which is supplied, the carbide in the basket is gasified at a high rate, and,

at the same time, the lime sludge, which is formed, is washed away. Hence with the " Spray " generator, the after-make which is caused in other generators by the lime sludge is virtually eliminated. After the spraying, the water runs back from the basket into the lower part of the main vessel where it is once more drawn up by the pump and delivered to the spray nozzle. This circulation of the spray water takes place as long as the lime contained in the water does not exceed some permissible value.

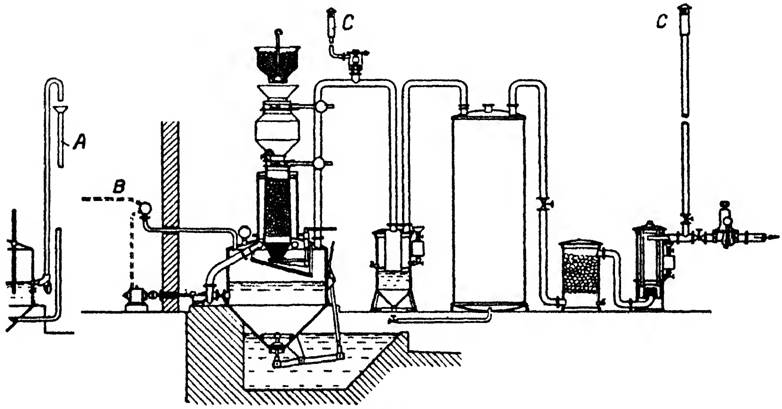


Fig. 16.—The " spray " generator

A, to sludge channel. *B*, from mains. *C*, *C*, through roof

Regulation of the acetylene production is obtained by means of a pressure control switch. This interrupts the current to the centrifugal pump motor at a definite maximum pressure of 1 atmosphere and switches in the current at a lower pressure. If production exceeds consumption the pressure rises in the generator and the centrifugal pump motor is switched off. If the pressure in the apparatus falls, due to the take, a pressure control switch switches on the current to the centrifugal pump motor. The spraying process starts once more and generation begins again. The pressure in the generator, therefore, varies continuously between the upper switching off and the lower switching on of the pressure control switch.

Fig. 17 shows a " Beagid " generator for small outputs. The water chamber *a* is filled with water up to the mark *A*, and the cartridges of " Beagid " *d* are placed in the frame *c*. The gas bell *b* is then put over this and both parts are forced into the water chamber. After

releasing the air for a short time, the purifier and hydraulic valve, which are permanently connected to one another, are screwed on and the gas take may begin.

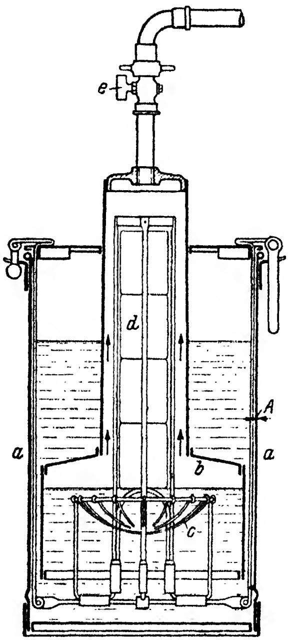


Fig. 17.—" Beagid " apparatus

a, Water chamber; *b*, gas bell; *c*, frame for *d*; *d*, " Beagid " cartridges; *e*, water cock.

The apparatus works on the displacement system and will produce only as much acetylene as is actually used. When the cock *e* is closed, the water is forced away from the " Beagid " and the production of gas ceases. When the take starts again the process controls itself automatically.

High output " Beagid " generators for an output up to 250 c. ft. per hour are constructed in a modified form.

Auxiliary Equipment for Acetylene Plants.—The acetylene which flows out of the generator is usually not fit for use without further treatment. There are still various chemical and mechanical impurities from which it must be freed, in addition to water vapour which is present in quantities which increase with increasing gas temperature. Moreover, it is frequently necessary to provide a special gas holder, in order to obtain unbroken, regular work. At other times it is necessary to fit a pressure regulator. In any case, the generator must be protected against oxygen getting back from the torch or against a back fire and this is assured by hydraulic valves which are prescribed by regulations. In large installations, pressure gauges and gas meters are fitted.

For generating gas, a range of auxiliary equipment is necessary, in addition to the acetylene generator, and this will be discussed in the following pages, from the point of view of construction, method of working and requirements of operating technique.

The Washer is responsible for separating small particles of lime which come over and also other mechanical impurities, in addition to freeing the acetylene from ammonia and hydrogen sulphide, which are always present and which can seriously impair the quality of the weld. In addition, it may be used with advantage for cooling the gas. This is seldom taken into account when fitting the washer.

In general the water seal, which is prescribed in paragraph 17 of the *Technical Principles of the Acetylene Association* for separating the generating space from the gas holder, should assume the duty of the washer. A water seal of this type is indicated as *f* in fig. 8. It consists of a gas-tight, closed container into which dip two pipes of different lengths. It will be realized that a container of this kind can only ensure adequate cooling and purifying of the gas when it is designed to dimensions which correspond to the quantity of gas used. This is usually not the case. With portable J apparatus it is never so. Consequently a cool and pure gas cannot be obtained from these generators. Too small a quantity of water which is quickly heated is consequently less capable of purifying the gas, since the ability of the water to dissolve the gas diminishes considerably with increasing temperature. Half the quantity of hydrogen sulphide is dissolved when the water is heated up from 50° F. to 105° F. (10° C. to 40° C.). The least that can be done is to take care frequently to renew the water in the seal pot. Wherever possible, however, a suitable washer of adequate size should be provided. It is only with a carbide to water plant, in which there is an adequate quantity of water, which takes over the work of the washer, that this precaution may be omitted. Even then it is advisable to renew the water frequently. It has been shown to be uneconomical to use again and again water which is saturated with gas in the hope of realizing savings in gas. When the gas is imperfectly purified, the saving in acetylene bears no relation to the expense of recovering the water.

The Purifier.—In addition to the impurities mentioned, acetylene contains hydrogen phosphide which it was previously thought necessary to remove, so that the maximum content did not exceed ·002 per cent. Accordingly acetylene installations were supplied with a chemical purifier. As a rule, it consisted of a cylindrical vessel filled with a purifying mass such as " Katalysol ", " Karburylen ", " Puratylen ", &c., through which the gas had to flow. If the mass is a powder, it is carried on cotton wool or pieces of felt which are laid longitudinally on perforated plates. If the material is in larger lumps it may be put on a perforated base plate without any intermediate layer and alternated with cellulose material, one layer above the other. The gas should not experience too great a resistance when flowing through the container, but should also be unable to channel. Containers which have a large surface area are the most suitable.

It has been shown, however, that little advantage is afforded by a chemical mass under present day conditions, since the size of the

purifier must be approximately that of the generator because of the velocities of flow which are used to-day. This is obviously unpractical.

In addition, the tests at the Technical Welding Research Department of the State Railways and the Chemico-Technical State Laboratories have established that the quantities of hydrogen phosphide in present day acetylene generated from carbide which is commercially obtainable, only amount from ·0025 to ·003 per cent, and have no appreciable harmful effect on the quality of the weld. This only begins to occur with quantities of hydrogen phosphide of about ·1 per cent.

In these circumstances, a chemical purifier can be dispensed with, in workshop equipment, and a source of danger is thereby eliminated, which would otherwise be set up by many purifying media, especially those containing chlorine. However, since mechanical purification is necessary in any circumstances, the purifier must be retained, but instead of filling it with a purifying medium it is recommended that it should be filled with broken brick or dust-free coke in order to dry the gas and hold up mechanical impurities. In this way a special *Drier* may be saved.

The *Gas Holder* which serves to store and distribute the gas under uniform pressure is usually built on to the generator of portable low pressure equipment and invariably on to the generator of a high pressure equipment, whereas in permanent low-pressure plants it is frequently erected separately. In this case, a floating bell is invariably fitted which is guided by side rails in order to ensure that the movement is regular and frictionless. Every gas holder must be provided with a safety pipe which leads into the open air. Pipes which pass through the base of the water vessel above the level of the sealing water serve to conduct the gas from the generator to the ancillary equipment, and the points where it is used. In order to obtain the necessary acetylene pressure, the cover of the bell is loaded, otherwise the bell is made as light as possible so that no important pressure variations occur due to its rising out of the sealing water and altering the pressure conditions.

Since the acetylene pressure in a container with a floating bell is limited to a relatively small amount, gas-holders with stationary bells are used in apparatus which is built for higher pressures and these function by displacing water or compressed air. This method is also adopted for equipment when it is desired to save space.

The size of the useful gas-holder space is proportioned according

to the quantity of carbide which may be consumed in the equipment. Up to a carbide charge of 1 cwt., ·32 c. ft. of gas holder space should be provided for each pound of carbide. For charges up to 2 cwt., ·24 c. ft. for each further pound of carbide should be provided, and for quantities greater than these ·16 c. ft. of gas holder space for each pound of carbide. This only applies to apparatus in which the carbide which is put in is not immediately gasified but comes in contact with the water in small quantities, depending on the control of the charging device worked from the gas-holder. For equipment in which the carbide is gasified at once, much greater gas holder space should be provided, and for every c. ft. per hour consumption, a minimum of 3 c. ft. of effective gas holder space should be available.

Where there is a high-pressure pipe line system of large output with numerous points, it will always be found that with continuous variations in consumption, constant pressure cannot be maintained. The welder is then compelled to regulate the torch frequently. In order to remove this undesirable state of affairs, a specially suitable Pressure Regulator is frequently installed, of which numerous types are on the market. In these circumstances the pressure reducing valve, which is described later, may be dispensed with. The welder then obtains a constant, regular gas pressure for the torch. In this way the work is considerably simplified.

*The Hydraulic Safety Valve.**—The main purpose of the hydraulic valve is to prevent oxygen getting back into the acetylene main and to prevent its passage into the generator and hence prevent the formation of a highly explosive mixture in the latter. If an explosive mixture of this kind, consisting of acetylene with oxygen or air, has already formed in the line, the hydraulic valve must damp down and choke any ignition which may occur at the tip of the torch. It may proceed as an explosive wave along the pipe line, so that in no case can it get back to the generator. In addition, the modern hydraulic valve is required to maintain the vacuum, which exists in the torch, and keep it constant by sucking in air. Hence the hydraulic valve is one of the most important accessories in an acetylene plant, and on its satisfactory working the safety of the plant depends. It is, therefore (in Germany), not only prescribed by regulation, but the design must be subjected to approval by the German Acetylene Association.

* Friedrich, "Hydraulic safety valves for gas welding plants", *Die Schmelzschweissung*, Vol. 8 (1929), pp. 129, 166 and 203. "Directions for the Construction of suitable Hydraulic Valves for High Pressure Acetylene Equipment", *Autogene Metallbearbeitung*, Vol. 24 (1931), Nos. 8 and 9, pp. 111 and 121.

The danger of oxygen getting back is very prevalent with low-pressure installations should the tip of the torch become choked. The oxygen which is under high pressure then tries to enter the acetylene line which is under low pressure.

Even when working with high-pressure acetylene, the danger of oxygen getting back into the line and of a blow back of the flame occurring is not impossible, although the danger of the oxygen getting back into the acetylene line at high pressure is not so great as with low-pressure acetylene.

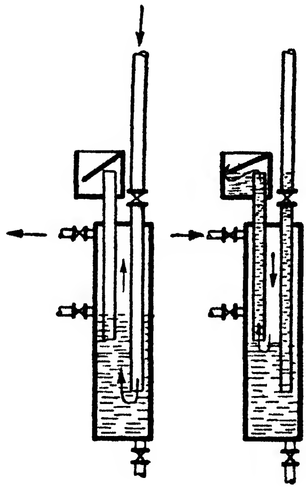
In order to guarantee the satisfactory working of the valve, an experiment is carried out when the design is tested to see whether it fulfils the following requirements:

1. Oxygen must be unable to get back to the generator.
2. Oxygen which gets back into the valve must escape to waste through the safety pipe and during this time only a small quantity of the water which is forced up should be lost.
3. The valve should prevent the possibility of air being sucked through the safety valve during normal working. On the other hand, air must be sucked through the safety valve if the requisite quantity of acetylene cannot be supplied from the apparatus. At the same time the drawing of air through the apparatus itself and the formation of a dangerous acetylene air mixture inside the gas bell must be avoided.
4. The carrying over of water by the gas stream through the valve must be avoided.

In its original form the hydraulic valve consists of a container which is partly filled with water and possesses a safety pipe in addition to the gas inlet and outlet pipes. The basic form of a hydraulic valve of this type is shown in figs. 18 and 19. Its mode of operation may be seen from the figures. The safety pipe does not dip so deeply into the sealing water as the inlet gas pipe from the generator. The gas outlet pipe is fitted above the level of the sealing water. If oxygen gets back from the torch, the sealing water is forced up so far until the lower opening of the safety pipe is clear of the water and the oxygen is provided with a path into the open air, whilst the inlet gaspipe is kept closed by the sealing water.

In general, hydraulic valves which have been in service up to the present time on low-pressure acetylene plants have been built according to this basic form. As long as too great calls were not made

on the output of the generator, they have fulfilled their purpose, provided they have been carefully looked after and maintained. The development of fusion gas-welding, however, has resulted in continually increasing quantities of gas being required in unit time as was not previously the case. Whereas hydraulic valves were usually tested for an hourly output of 15 c. ft., to-day quantities from 150 c. ft. per hour up to 300 c. ft. per hour are nothing out of the ordinary.



Figs. 18 and 19.—Lay-out of hydraulic valve

Fig. 19 (right) shows the way in which the valve works when oxygen gets back from the torch.

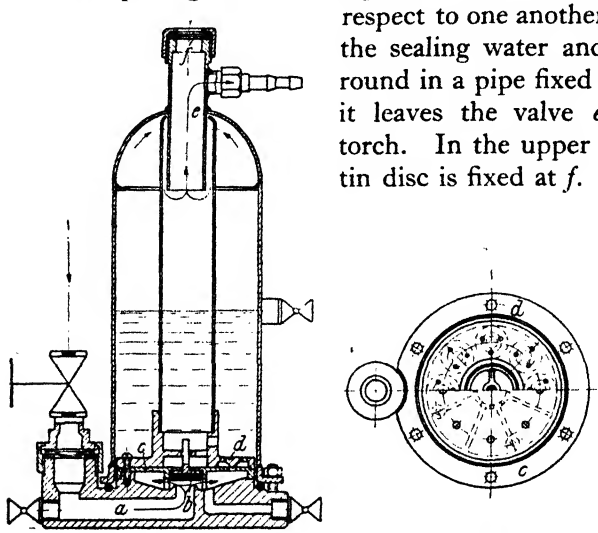
With these high velocities of flow, the gas coming from the generator may rise in large bubbles through the water and form a gas path through which a back fire from the torch may easily find a way to the generator without the hydraulic valves functioning.

It will, therefore, be recognized that old designs of hydraulic valves do not afford that degree of safety, on large consumptions, which is necessary and consequently new developments have had to take place. The first step in this direction arose with the provision of the high-pressure generator. At the outset hydraulic valves were required which afforded a higher degree of safety. The solution, in this instance, was simpler than for low-pressure hydraulic valves, since methods could be adopted which resulted in a higher pressure drop in the hydraulic valve. This pressure drop may be neglected for high gas pressures, but if introduced for low gas pressures it would result in the low available pressure in the line being completely dropped through the hydraulic valve.

The method used consists essentially in obtaining a fine atomization of the gas stream when it passes through the sealing water in the hydraulic valve by providing a large number of narrow inlet holes, so that the formation of a continuous gas stream is prevented. Conversely oxygen which gets back into the valve is prevented from passing through the pipe into the generator. As a rule a non-return valve is fixed in the valve, or the pipe leading to it, which is shut by the pressure of any explosion wave which may be set up, and this seals the path to the generator.

A very well known type of high-pressure hydraulic valve of this kind is shown in figs. 20 and 21.

The gas stream enters through the passage *a* and lifts the non-return valve *b*. It enters the valve in the atomized state through the narrow openings in the baseplates *c* and *d* which are staggered in respect to one another. It flows through the sealing water and is once more led round in a pipe fixed in the valve, before it leaves the valve *e* and reaches the torch. In the upper pipe of the valve a tin disc is fixed at *f*. Oxygen which gets back from the torch will force down the non-return valve by the pressure on the water column and hence seal the path to the generator. An explosion wave coming from the torch will act in the same way, and, in view of the high pressure which is set up, the tin disc will be burst and a direct path into the open air will thereby be provided.



Figs. 20 and 21.—High-pressure hydraulic valve

a, Gas inlet passage; *b*, non-return valve; *c* and *d*, base plates with staggered openings; *e*, outlet for the gas; *f*, tin disc.

Fig. 22 shows another high-pressure valve. The non-return valve is fixed in the main which comes from the generator to the hydraulic valve. The atomization of the acetylene, which enters the hydraulic valve, is obtained by providing a large number of small holes in the ring-shaped inlet pipe. The high-water column also serves the purpose of stopping oxygen which may get back or of sealing the path of an explosion wave. If this occurs, it exerts a pressure on a membrane which is attached to the base and presses it downwards. When stationary it is forced upwards by means of a spring. In this way a blow-off valve, which is fixed on the cover of the hydraulic valve and attached to the membrane by means of a link, is opened and the oxygen or explosion wave may escape into the open air. The valve also avoids the use of the tin disc described in the previous type. Since the changing of the tin disc, which may be damaged

by a back fire, always entails an interruption in the work of the welder, and, as the tin disc is easily broken and may be damaged mechanically, and has, therefore, to be specially protected, it was thought that, by providing a blow-off valve for this hydraulic valve, an improvement would be made as compared with the hydraulic valve with the tin disc. Practice, however, has shown that, partly due to the inertia of the spring required for the membrane, and partly due to the inaccessibility of the rubber plug forming the blow-off valve, which frequently stuck, especially when it got old, the

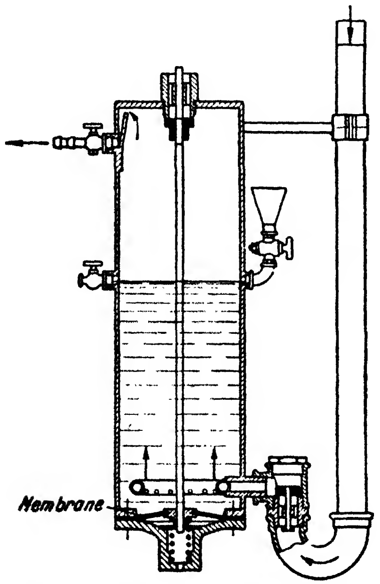


Fig. 22.—High-pressure hydraulic valve

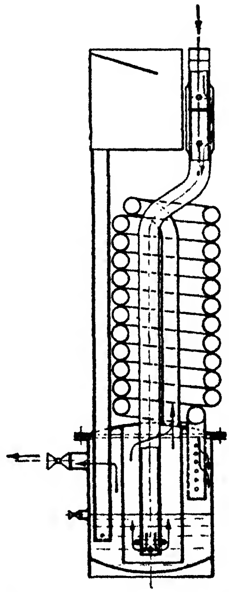


Fig. 23.—New type low-pressure hydraulic valve

valve did not open or only opened slowly. This resulted in the bursting of the hydraulic valve because of the explosion wave. Consequently valves of this type cannot be recommended.

On account of the large pressure drop which is set up, these valves cannot be used for low pressure installations. Where longer mains for large generators exist, steps may be taken to increase the acetylene pressure by using compressors, as has been mentioned. The welding booths may then be provided with high-pressure valves. By means of a Prize Competition, the Technical Committee for Welding Technology is engaged in developing a suitable low-pressure hydraulic valve which will afford adequate safety in all

cases, especially for small generators, where it is not possible to provide a compressor, as well as for the high gas consumptions which are required at the present time. The testing of the suggestions which have been received has now been completed, so that it may be assumed that in a short time a number of low-pressure hydraulic valves will be put on the market which accord with the requirements specified.

One low-pressure hydraulic valve of this type which may be used is already available commercially; this is shown in fig. 23. In contrast to previous low-pressure valves, the vessel of the valve is so divided that the acetylene entering from the generator is conducted through a pipe having a throttling device at one end, and finally reaches the inner vessel. From here it must flow out through a coil, which has a further throttling device at the other end, before it reaches the outer chamber of the hydraulic valve. It then passes through the main to the point of consumption. The inner chamber is directly connected at the bottom with the sealing water so that the water stands at the same height in both chambers.

If a back-fire occurs, the water in the valve is forced into the inlet pipe through the throttling device so that a further flow of gas into the valve is prevented before the explosion wave can find another path through the coil and from there into the inner chamber of the valve to the generator. The excess pressure is relieved in the usual way through the safety pipe which leads into the open air.

The valve also functions if the vacuum at the point of consumption varies. The atmospheric pressure overcomes the $\frac{3}{4}$ in. water column in the safety pipe and allows air to blow into the valve to equalize the pressure.

3. The Installation, Working and Maintenance of Acetylene Plants.*

There are Home Office regulations governing the manufacture, supervision and use of acetylene, as well as for the storage of calcium carbide. All managers of works in which acetylene gas is used, and the personnel which is responsible for examining and maintaining of plants, should be acquainted with every detail of these.

In the following reference is made to some important points.

Anyone desirous of manufacturing acetylene or storing calcium carbide must report the matter to the local police officials. It is also necessary to report the undertaking of important modifications

* The regulations referred to are those in force in Germany.

to the plant, whether it is to be permanently out of commission or not, and important modifications to the generator station. In addition, important modifications to any standard type of generator require the permission of the German Acetylene Association. For example, unless permission has been obtained, it is not allowed, as is often done, to load the bell of the acetylene container in order to increase the gas pressure above that value corresponding to the type of construction, in the event of there being an insufficient pressure at the torch.

Acetylene generators having a maximum filling of 22 lb. of carbide and up to a maximum hourly output of 225 c. ft. of acetylene, which may be used in workshops (portable generators), are only permitted after a special test of the type by the German Acetylene Association. This applies to all acetylene generators independently of their size, in which there is not a variable capacity holder. All other generators may be subjected to an optional test on request. The test also applies to the hydraulic valve.

Workshops, in which portable generators are used, must be provided with air purification equipment and for each generator they must have a minimum of 2000 c. ft. air space and 210 sq. ft. floor space. The generators must be placed at least 10 ft. from an open light or fire and 20 ft. from other generators.

Permanent acetylene generators having a charge of more than 22 lb. of carbide may be erected only in special generator rooms. Portable generators of this type may be used only in the open air. The general use of acetylene generators in the open air is only permitted when there is no danger of freezing. These special buildings must have fireproof walls and a light roof. They must be provided with good ventilators on the roof and protected against frost unless the generator has been made frost-proof. Media for protecting generators against frost must not attack the generator shell.

Buildings must have adequate daylight in order to enable any work to be carried out without artificial light. It is forbidden to enter the building with a light or glowing object (smoking).

Pits for lime sludge must be so arranged that acetylene which may be given off cannot enter into closed buildings. Open pits are to be railed in; those with tight roofs are to be provided with efficient ventilating equipment.

Carbide may be stored only in dry, water-tight sealed drums. The opening of the drums with soldering equipment or tools which may cause sparks is forbidden. In general, only one carbide drum

may be open in each store. Drums which have been opened are to be kept covered with a water-tight cover which may be closed or clamped on. There are special precautions relating to the storage of large quantities of carbide.

Only general advice can be tendered for the running of an acetylene plant. The special working instructions which are provided by the suppliers with each apparatus are to be observed.

Before putting the plant into commission, each piece of individual apparatus, such as the generator, gas holder, water seals, hydraulic valves, should be filled with water according to instructions. If it is suspected that there are leaks, the places concerned should be brushed with soapy water and in no case tested with a flame.

When the carbide is put in, care should be taken with carbide to water equipment to remove pieces of ferro-silicon and leave carbide dust behind. With water to carbide equipments the sliding drawers should be filled only full enough to provide adequate room for the carbide sludge which is formed and which requires a greater volume. With " displacement " equipment care should be taken to ensure that the grading of the carbide corresponds with the type of basket used.

The gas which is first generated is sent into the open air, since it is always mixed with air and forms an explosive mixture. The generator should not be overloaded, as it is very easy to set up an undesirable temperature rise. The escape of gas into the building should not amount to more than ·1 c. ft. per hour. The sludging of the generator should be carried out regularly and, at the same time, fresh water should be put in.

The hydraulic valve should be examined several times a day to see that the water level is as prescribed. It may be put into commission when the water flows out of the test cock with the gas inlet cock shut and the gas outlet cock open.

In the *Maintenance* of a plant it should be carefully noted that repairs, in which fire or hot or glowing tools are used, may be undertaken only when the vessel, in which some acetylene may remain behind, has previously been filled with water and carefully cleaned out. Blowing out the generator is insufficient. After the apparatus has been cleaned, it is preferable to leave it standing for some time filled with water so that every trace of acetylene may be removed. The repair work should only be carried out in the daylight and with portable equipment only in the open air. Frozen equipment should

be thawed only with hot water or steam and not with fire or any hot objects.

Great care should always be taken when working on an old generator and also on one which has been out of commission for a long time. There have been generators which, after being out of use for many years, have exploded, as soon as work was undertaken on them, with a view to putting them in commission. Consequently repair work should be carried out only by experienced workmen.

The generator should be painted from time to time and normal oil paint should be used externally and pure asphalt tar internally.

4. Steel Cylinders for Compressed Gases and their Auxiliaries.

Oxygen, hydrogen and dissolved acetylene for welding purposes are supplied in steel cylinders. As a rule these are 8¼ in. in diameter and about 6 ft. high, and have a capacity of 1·4 c. ft. of water and 200 c. ft. of gas.

Steel cylinders should be made from the best steel having a maximum yield point of 28·5 tons/in.^{2} and 35–40 tons/in.^{2} tensile strength and 12 per cent elongation. They are made either from seamless tubing or from pilgered billets by the hollow forging process. As a rule the filling pressure is 150 atmospheres for oxygen and hydrogen and 15 atmospheres for dissolved acetylene. Fig. 24 shows the appearance of a cylinder. Cylinders must have a base ring in order to prevent them from rolling about.

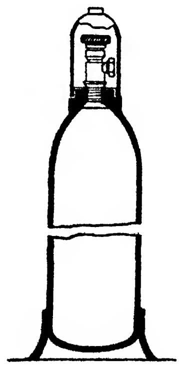


Fig. 24.—Section through a steel cylinder

A Home Office regulation of 1st October, 1921, concerning the transport of liquefied and compressed gases governs all matters relating to these cylinders. Not only is the manufacture governed by official specifications, but it is also laid down that, with certain exceptions, the cylinders must be subjected to an official test every five years at the most. The German State Railways not only test cylinders by illuminating the interior, but also by means of X-Rays. By this test, not only have a large number of dangerous corroded spots been found on the cylinder walls but, in addition, serious fractures have been discovered in the base. A new decree for high-pressure gases is in course of preparation and this will be valid for the whole State.

The steel cylinders are closed by means of a screw-down valve

which must not be taken off by the consumer. In addition to sealing the cylinder, their main purpose is for coupling on, as simply and safely as possible, an adjustable pressure-reducing valve for controlling the gas take and providing the necessary pressure for welding. In order to avoid getting these cylinders mixed, it is prescribed by regulations that the connexion on the cylinder valve for the pressure-reducing valve has a right-hand thread for oxygen and for combustible gases, with the exception of acetylene, which has a left-hand thread. A clamped coupling is prescribed for acetylene. In addition, it is recommended that the gas cylinders should be

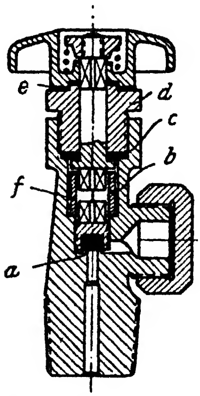
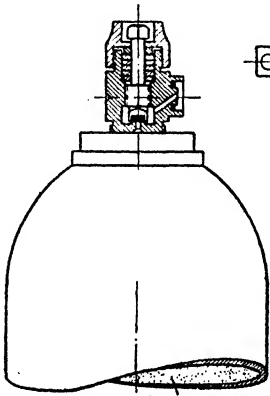
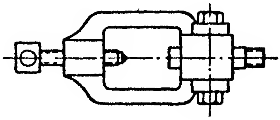


Fig. 25.—Cylinder valve for an oxygen cylinder

a, Hard rubber plug; *b*, brass sleeve; *c*, packing disc; *d*, guide nut; *e*, guide ring; *f*, muff coupling.





Figs. 26 and 27.—Acetylene cylinder with clamp connexion

clearly indicated by means of a coat of paint on the outside. In this case, cylinders should be painted blue for oxygen, red for hydrogen, green for nitrogen, white for acetylene, and grey for all other gases. A coat of paint should cover the whole surface of the cylinder.

Fig. 25 shows the cylinder valve which is used for oxygen cylinders. Sealing is provided by a hard rubber plug *a*, which is fixed on the lower portion of a double spindle. If the upper spindle is turned by means of the handwheel, the lower is withdrawn by means of a removable brass sleeve and the sealing packing is, therefore, raised or lowered. The inside of the valve is kept tight by means of a packing disc *c*, which is kept permanently pressed against a guide nut *d*, by means of a spring. Since this packing has occasionally to be replaced on a full cylinder, on account of damage and use, the upper portion of the spindle may be taken out by unscrew-

ing the guide nut *d*. After having pressed the sealing packing *a* hard on its seat the damaged packing may be removed and replaced. In addition to cylinder valves of this type other simpler valves having continuous spindles and gland valves are used. These are suitable for acetylene cylinders when provided with a clamped connecting piece, since the latter are at a lower pressure than, for example, oxygen cylinders. Figs. 26 and 27 show a simple valve of this kind, along with the clamp connecting-piece belonging to it. The spindle carrying the sealing plug is removed by means of a spanner.

Since there is a possibility of rusting, valves for oxygen must have no internal steel parts. Iron oxide, combined with oxygen under pressure, may cause ignition. The parts are, therefore, made of brass or bronze. Conversely, sealing valves for acetylene cylinders must not be made of copper, which forms explosive compounds with acetylene, but must be made only of steel.

The following points regarding the handling of cylinders and cylinder valves are specially to be noted.

Oil and grease in contact with oxygen under pressure tend to ignite and cause explosions. These materials, as well as talc, paraffin and leather packings, should be avoided at all costs. Even oily rags or greasy hands may be sources of danger.

If large quantities of oxygen are taken from the cylinder, for example, when a large welding torch is connected to it, or during cutting, freezing of the cylinder valve may easily be caused on account of decreased temperature set up by expansion, and this may cause the water which is always contained in oxygen, to freeze. This freezing may easily be observed by the formation of hoar frost and the backward movement of the pressure gauge needle. Consequently, cylinders should not be emptied in less than half an hour. This corresponds to a maximum take of 7 c. ft. per minute. If the valve is frozen it should not be thawed by means of a flame or incandescent tool.

Similarly not more than ½ c. ft. of gas per minute should be taken from an acetylene cylinder. The reason for this is different, and is due to the fact that, with large gas takes, acetone is drawn over from the cylinder. If the consumption of oxygen or acetylene is greater than the figures given, several cylinders must be connected together.

The cylinders should be treated carefully and, above all, they should not be thrown about. This precaution should be observed,

especially in winter because of the brittleness of the cylinder material. They may be protected against accident by suitable cylinder containers or stands.

For transport purposes, it is preferable to lay the cylinders flat, and during working it is most convenient, especially with oxygen, to place them in the horizontal position. On the other hand, cylinders of acetylene should never be laid flat during working, otherwise the acetone will flow out. In conclusion, the cylinders should be protected against artificial or natural heating as the gas is already subject to a sufficiently high pressure and any increase of pressure due to heating may lead to damage.

Pressure Reducing Valves.—For welding purposes the pressure under which the gas stands in the cylinder must be reduced. For this purpose a pressure-reducing valve is provided for each cylinder.

It consists essentially of the following parts: A high-pressure connecting-piece, with connecting screw and high-pressure manometer and a low-pressure part with a control screw, working pressure gauge, safety valve and stop valve. It also carries the hose connecting-piece.

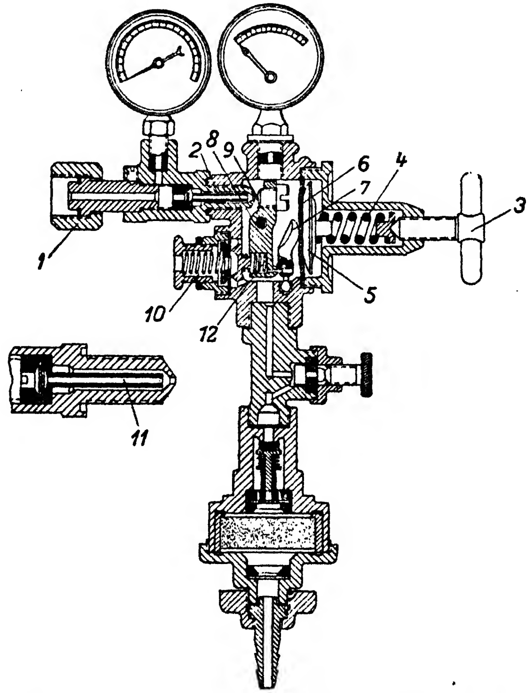
Different valves for greater or less pressure reductions are necessary for cutting and welding purposes. The valves are clearly distinguished by means of a coat of blue paint for oxygen, red for hydrogen, and white for acetylene.

Figs. 28 and 29 show a very common design of a pressure-reducing valve for oxygen. It works in the following way. The pressure-reducing valve is connected to the cylinder valve by means of the nut 1. When the valve is opened, the gas flows through the passage in the connecting branch as far as the narrow pressure-reducing channel 2, and, at the same time, indicates the pressure in the cylinder as it is connecting with the high-pressure manometer. By turning the handwheel 3, the spring 4 is compressed, and this in turn acts on the metal disc 5, the rubber membrane 6 and the links 7 and 8 causing the exit nozzle 9 to open. The gas now flows into the low-pressure housing until the pressure in the housing is higher than that corresponding to the setting of the spring 4, whereby the locking spring 12 starts to function and forces the link carrying the hard rubber plate hard against its seat. At the same time, since a pressure drop is set up, due to the oxygen flowing through the valve, the membrane 6, which is loaded with the pressure of the control spring 4, is only compressed, until spring 4 again overcomes the back pressure of spring 12 and, therefore, gas may escape from the

cylinder. The working pressure gauge indicates the pressure in the low-pressure chamber.

In order to prevent the pressure from rising above a definite amount, on account of lack of tightness or damage to the valve seat at 9, a permanent safety valve 10 is fitted which should not, however, be fitted to the flange itself as is shown in the figure. This requirement is fulfilled in newer designs of valves.

In addition, the sleeve 11 is fitted in the connecting piece before the expansion passage, in order to protect the pressure reducing valve against the danger of being burnt out. It works by conducting away the heat of compression which is generated in the nozzle when the cylinder valve is opened and in this way the ignition temperature of the hard rubber is not attained. There are other equally suitable safety devices for preventing burning out, for example, turbulent flow nozzles, but felt packings have not proved suitable.



Figs. 28 and 29.—Section through a pressure-reducing valve

1, Nut; 2, expansion passage; 3, hand wheel; 4, spring; 5, metal disc; 6, rubber membrane; 7 and 8, levers; 9, exit nozzle; 10, safety valve; 11, fire-protecting sleeve; 12, spring.

In addition, the propagation of an explosion from the torch side may be prevented by coupling in a safety cartridge. This is screwed on to the controlling cock, i.e. on the low-pressure side of the reducing valve. The hose is connected from this to the torch. The non-return valve which is fixed in the safety cartridge allows the gas to flow only in the direction of the torch and prevents a return flow, and while the gas may flow through the fireproof porous filler material with its numerous small channels it holds up an explosion

wave which is travelling from the torch through the hose and brings it to rest. It should be tested against striking back, and there is also the danger of breakage during transport.

Pressure reducing valves of the type described are unable, however, to maintain a uniform pressure over a long period of time. On account of the gradual reduction of the cylinder pressure, the sealing spring 12 opposing spring 4 is subjected to a greater load, and this can only be neutralized by adjusting the handwheel 3 which actuates the back pressure spring 4. In order to prevent a reduction in the working pressure, various methods have been propounded.

In modern constant pressure-reducing valves, the method is to replace the lever link, which is inside the valve previously described, by a helical spring which, at the same time, fulfils the function of the sealing spring and is so controlled by the pressure existing in the cylinder at the time, that it presses more or less strongly against the packing seat so that it is unnecessary to carry out any subsequent adjustment.

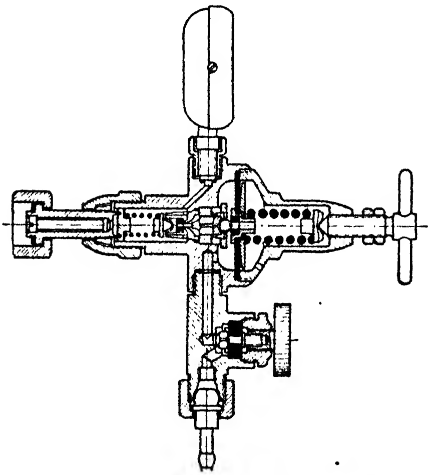


Fig. 30.—Constant-pressure reducing valve

Recently, single- or double-stage piston valves have made great headway. Fig. 30 shows a valve of the former type, the mode of operation of which may be clearly seen from the drawing. An adjustable membrane, which is guided by a spring, has also been provided in this type. When the valve is adjusted it presses through a sphere on to a piston, which is fixed in the middle of the valve and, by means of a thrust link, which bears on a centre which is made of metal to increase its life, this in its turn pushes the hard rubber seal plate and so opens the valve. When the pressure in the valve has risen to such an extent as to overcome the resistance of the membrane spring, the closing spring presses the sealing plug on its seat again and closes the valve so that the piston returns to its initial position. When the pressure in the valve tends to sink, the process starts once more.

If the pressure in the valve rises due to diminution in the take below a certain amount, the membrane is forced out of its normal position. The piston does not move along with it, and consequently the sphere is raised off its seat on the membrane and the gas may escape through the opening into the outer chamber and hence into the air. This arrangement describes the safety valve.

A vertical type of piston valve is also made. Double stage valves consist of two single-stage valves which are similar in their operation and are built in series. The former stage usually reduces the pressure automatically to 15 atmospheres and cannot be regulated externally except by special adjustment. This arrangement has the advantage of providing a perfectly straight line pressure distribution even at low temperatures. In addition, it provides the best protection against burning out the valve. In the first stage, which is provided with a rather larger outlet for the oxygen which passes through it, there is no possibility of heating up the hard rubber sealing plug to the dangerous ignition temperature of 510° F. (265° C.), since the piston is always raised off its seat, depending on the pressure reduction, and the heat can be conducted away to the body of the valve. In spite of the narrower inlet hole in the second stage, no compression can take place which is sufficiently large to raise the gas to the ignition temperature.

The Welding Torch.—The welding torch, termed " Torch " for short, is the welder's tool for fusion gas welding. Good work may only be expected when the welder is provided with a sound torch and when it is always kept in good condition. As there are a large number of torches on the market which do not fulfil all the conditions required of them, care must be taken when selecting one. In the following pages are detailed the main points to which attention should be given.

The torch is responsible for mixing intimately the oxygen and whatever combustible gas may be used, and enabling the correct setting of the most suitable flame for welding to be obtained. It should be easily manipulated and not too heavy so that the welder is not hindered or fatigued during his work.

In all torches the main chamber is designed as the handle and to this are fitted the pipes for oxygen and the combustible gas. The mixing pipe with the torch tip is connected to the handle pipe, and in this pipe the mixing of the gases takes place. Pressed brass is usually used as the material for the handle and the mixing pipe and recently various light metals have been used. Copper is used

for the torch tip. Care should be taken that the design of screwed parts and the tips is robust and clean. The inner parts should be easily accessible and, most of all, the weight should be evenly distributed fore and aft the handle.

Both gas pipes are provided with a suitable closing device in the shape of a cock or preferably a valve. The acetylene valve, at least, should be situated near the hand which guides the torch, so that it may be comfortably operated during welding, should it be found necessary to regulate the supply of gas. In old types of torches the closing device is often found behind the hand. For the reasons which have been given this is unsatisfactory.

If the gases are fed into the torch at different pressures, the oxygen, which is at a higher pressure, is responsible for drawing in the acetylene in quantities which should be at least equal to the quantity of oxygen for any setting. This is achieved by means of an injector with a mixing nozzle, similar to the steam or water injector. If acetylene at a higher pressure is available it may be supplied at the same pressure as the oxygen and, in this case, a simple mixing nozzle is sufficient and the injector principle may be dispensed with.

As a rule, a distinction is made between (*a*) Injector torches, (*b*) Mixing nozzle torches, because of their different methods of working.

From what we have previously said, it will be realized that these terms do not correctly indicate the way in which the torch works. The injector is also coupled with a kind of mixing nozzle so that the gases may be intimately mixed with one another. Equally unsatisfactory is the distinction between low-pressure and high-pressure acetylene torches, since the injector torch is frequently used for high-pressure acetylene and, in this case, the acetylene pressure is set at a slightly less value than the oxygen pressure. It is preferable, therefore, to distinguish between them as follows: (*a*) Injector torches, (*b*) Injectorless torches.

Fig. 31 shows the layout of an injector torch. The main part is the injector, through the central opening of which the oxygen flows at high velocity under a pressure of between 15 and 45 lb./in.^{2}. In this way, the acetylene, which is at a lower pressure, is drawn by the injector through the surrounding annular space. Both gases then mix in divergent conical portions of the pipe and, since the exit opening diameter of the torch tip is less, the velocity decreases and the pressure in the mixing pipe rises. This pressure is converted into exit velocity at the exit from the tip of the torch.

This opportunity will be taken to point out a disadvantage in the construction of the torch as is shown in the layout. The acetylene is led in through the handle pipe itself, and this is situated before the injector. The oxygen pipe is enclosed in the handle pipe and is surrounded along its whole length by the acetylene pipe. With this arrangement, there is the danger that the oxygen may get into the acetylene line, which is at a lower pressure, if the pipe, which has

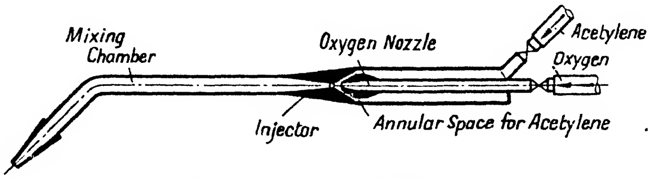


Fig. 31.—Lay-out of an injector torch

been provided for it, proves for any reason not to be tight. Hence, attention should be paid to the provision of a special line for the combustible gas as well, which should be placed alongside the handle pipe as far as the injector nozzle and only then should it feed into the annular space. Holes which are drilled in the handle pipe will allow gas to escape into the open air, should leaks occur.

Various drawbacks which are associated with the injector, and which will be discussed in detail in the following pages, have resulted in a return to the injectorless torch for use with acetylene, of the

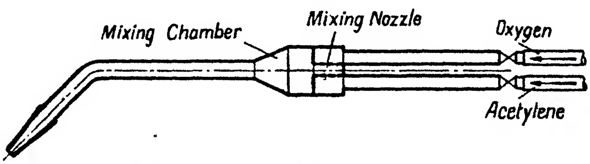


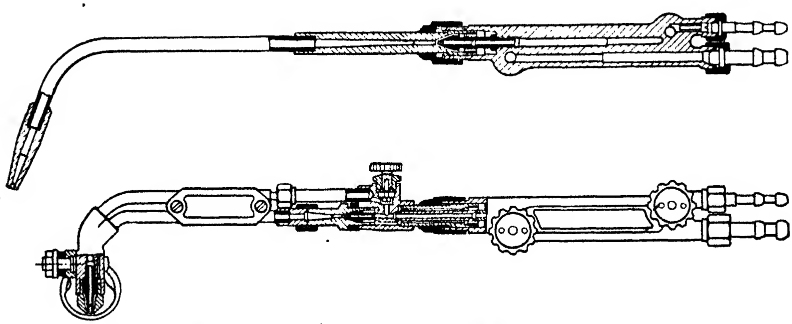
Fig. 32.—Lay-out of an injectorless torch

type which is used with hydrogen. This only occurred when success had been achieved in supplying acetylene at a higher pressure.

The layout of an injectorless torch (mixing nozzle torch) is shown in fig. 32. Oxygen and acetylene enter the mixing nozzle through separate pipes. In order to ensure a neutral flame, the gases are led to the torch at approximately the same pressure. The processes which take place in the mixing nozzle and at the outlet through the tip are similar to those which occur in the injector torch.

In order to be able to use a suitable flame, both for injector torches and injectorless torches, corresponding to the various thick-

nesses of material, and the heat conductivity of different metals, it must be possible to change the mixing pipe, and, in any case, the torch tip. Admittedly there are torches which are not provided with devices of this kind, and these are known as Non-variable Torches. They are only used in places where a definite type of weld is frequently repeated, for example, on mass production work or on use with plates of limited thicknesses. In other cases, if non-variable torches are being used, one torch must always be exchanged for another if a new piece of welding work is necessary or if a stronger or weaker flame is required. In general, therefore, non-variable torches are not satisfactory.



Figs. 33 and 34.—Combined welding and cutting torch

The usual arrangement is to supply a torch with interchangeable tips. These torches are termed *Variable Welding Torches* in contrast to the non-variable torches. Consequently, there is a considerable difference between injector torches and injectorless torches. In the latter case only the screwed tip is changed. As a rule a set of 4 to 8 interchangeable tips are supplied for various flame strengths.

For injector torches, however, it is insufficient to change the tip alone, since the dimensions of the injector and the size of the passages in it must bear a definite relation to those of the mixing pipe. Consequently, in injector torches, the mixing pipe is made in one piece with the tip and the injector is made in one piece with the mixing nozzle, and these are made interchangeable. Figs. 33 and 34 show an injector torch which can be converted into a cutting torch by means of a suitable fitting, and this will be discussed in greater detail in the third part of the book. The oxygen nozzle forms a tight joint with a conical face which provides a seating for it in the handle pipe. Since it is quite easy to get a leak at this place which will allow the oxygen to get back into the acetylene line and

result in the formation of an explosive mixture, special care should be taken to ensure that the welding tip sits tightly on its seat. So-called safety variable head welding torches, which are supposed to overcome the danger by conducting the oxygen into the open air, should a leak occur at the seat, have proved unsatisfactory.

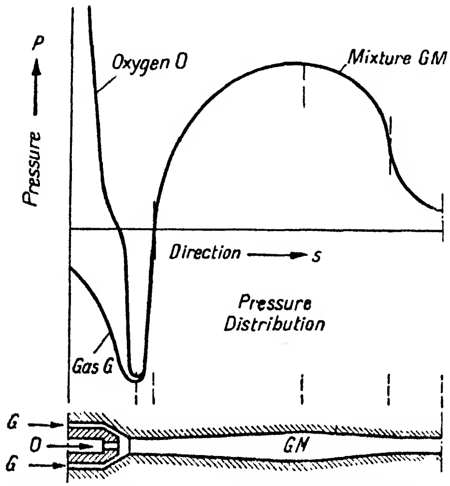
The danger of the oxygen getting back into the acetylene line exists with all torches and this may also be caused by blocking up the tip through impurities or by unskilled lighting or shutting off of the welding flame.

There is also the further danger, which is especially existent in low-pressure installations, in which the acetylene gas is at a lower pressure than the oxygen, that a highly explosive mixture of acetylene and oxygen may form in the acetylene line and may result in an explosion wave, if a blow-back occurs in the torch.

It is very easy for a flame to strike back inside the torch, when the torch is heated and this cannot always be avoided. It is necessary that blow-backs should not pass farther along than the mixing pipe and they should be damped down there and further combustion of the flame inside the torch should be prevented. This may be achieved by suitable design, by making the inlet and outlet diameters for the gases in the nozzle and tip of a definite ratio, which has been determined by experience. In general, all torches to-day are virtually safe against back firing. One can convince oneself of the degree of safety of a torch against back firing by holding it in a narrow angle formed by two plates, or at one end of a closed pipe, so that the heat of the flame is thrown back on to the torch. It is better still to test the safety against back-firing by closing the torch tip suddenly, by extinguishing the torch through holding the tip against a plate. This method is also useful to test the loss of suction with increasing temperature.

With injector torches, the heating of the torch has another effect, viz. to alter the mixing ratio between oxygen and acetylene, so that excess oxygen is obtained. The welder has then to regulate the torch to give a neutral flame. In many torches, this phenomenon increases with increasing temperature to such an extent that finally it is absolutely impossible to obtain a ratio of oxygen to acetylene of 1 to 1. Such torches then continue to work with excess oxygen and the weld can very easily be spoiled. This phenomenon has been given the name of " Dilution ", and it has been explained by stating that with increasing temperature the density of acetylene is reduced to a greater extent than that of oxygen and consequently the latter

is unable to suck through the same quantity of acetylene. *Investigations* of the Technical High School in Aachen as well as at the Chemico-Technical State Laboratory, Berlin, and the Technical Research Laboratory of the State Railways, Wittenberge, have shown that the reason for this is to be found in the variations in pressure which are set up in the torch.* Pressure in the mixing pipe is the factor controlling the reduction in injector capacity of the torch. As soon as the pressure rises on account of the heating of the mixing pipe and the consequent expansion of the gas, which acts uniformly in all directions, experiments have shown that the vacuum before the injector nozzle, and consequently the suction, decrease in the same ratio since this increase in pressure primarily affects the acetylene which is entering at a lower pressure. From the curves in Figs. 35 and 36 the processes which occur will be quite clear, if it is borne in mind that the zero line is displaced downwards when the torch is heated. In consequence, the pressure in the mixing pipe is increased and this results in a diminution of the vacuum before the injector nozzle which decreases almost to zero and causes the loss of suction capacity.



Figs. 35 and 36.—Lay-out and pressure distribution in an injector torch

G, Gas; *O*, oxygen; *GM*, mixture

Up to the time of writing there are few torches in which the injector effect remains sufficiently constant with large increases in temperature, that a neutral ratio of oxygen to acetylene can be maintained. Success can only be achieved in this direction by suitable design based on experience and, as yet, the matter has not been completely cleared up.

When low-pressure acetylene is being used, good torches with a high suction capacity are definitely to be preferred. It must, however, be pointed out that, with most torches the suction capacity

* Wallichs and Mues, " The Behaviour of the Welding Torch during a change of Pressure conditions between oxygen and acetylene ", *Autogene Metallbearbeitung*, Vol. 22 (1929), p. 146.

cannot be completely maintained if, at the same time, the necessary safety against striking back is provided. One of the two is always gained at the expense of the other. Consequently, with injector torches, which are to be used with acetylene at high pressure, more stress is laid on their safety against striking back than on their suction capacity, as this is not so important because high-pressure acetylene will always continue to flow even if the vacuum before the mixing nozzle is reduced. It will, of course, always be necessary to regulate the torch when it heats up. In some cases this unfortunate state of affairs has led to the adoption of the injectorless torch which is used in oxy-hydrogen welding, since it was thought that it would not be necessary to exercise the same degree of control, as both gases are available at the same pressure. It should not be forgotten, however, that this torch has also to be regulated because of changes in pressure in the acetylene or oxygen line. In consequence, opinions vary, to-day, as to whether the injectorless torch, with high-pressure acetylene, is definitely preferable, providing special precautions are taken to ensure equality of pressure and quantity. This quality has been sought in a special design known as the " Frama " torch.

This consists of a mixing nozzle torch, provided with a throttling device where the gases enter and this may be adjusted to give a definite flame size and to ensure that equal quantities of both gases flow in, so that the theoretical mixing ratio is available.

Another special design is the two-flame torch which has recently been introduced into various countries. The object of this is to increase the welding speed. A most excellent design is that which has at the end an asbestos covering which is common to both tips. In order to protect the covering against damage it is surrounded by a light copper sheath. If this end piece is dipped in water before welding, the insulating material becomes saturated with the water so that, due to the vaporization of the water during welding, a cooling effect of the tip is obtained by the absorption of heat.

Torches with three or more flames have also been constructed. Since it is difficult to observe carefully a large number of flames and since the advantage which is obtained with the two-flame torch is not essentially improved upon, torches of this type are less to be recommended.

Handling of the Torch.—From what has been previously stated, it is obvious that the welding torch is a very sensitive tool, and must accordingly be handled with care, if it is hoped to carry out satisfactory work with it. Care should be taken to see that it is protected

against injury, when it is being used. If long interruptions in the work occur, it is better to put it in a special tool-box which is used to hold the welding tips and other fragile welding accessories. In order to relight the flame the welding bench is provided with a small light.

If welding work is carried out at various places, it is better to use matches for lighting the flame, and the welder can carry these with him.

When hydrogen, illuminating gas, benzine and benzol vapour are being used, the combustible gas is first lit and then the oxygen is turned on. Conversely, when the work is finished, the oxygen is first turned off and then the combustible gas. With the acetylene torch, the position is reversed. The valve in the oxygen pipe is first opened, and then that in the acetylene pipe, and it is only lit when the gases have mixed. If the same procedure were adopted as with the previously mentioned gases a dirty, sooty flame would be obtained from the acetylene. When the torch is put down, the acetylene is first turned off and then the oxygen. If a back-fire occurs the gas line is first shut and then the oxygen line and a short wait should be made before lighting the torch again. With a design which is safe against back-firing, the torch tip may be rubbed, without risk, on a piece of wood in order to clean the tip.

If the torch has got choked up during working, the copper tip must only be cleaned with a copper needle or a piece of sharpened wood, otherwise the nozzle diameters will be increased and the tip will soon be rendered unfit for service. Spots of soot which are caused by back-fires may best be removed by washing down with soapy water, benzine or potash lye. A warning is here given against the use of reamers.

Finally a sufficiently large vessel of water should be kept on the welding bench so that the torch may be cooled from time to time. It is frequently necessary to cool down the torch when work is being carried out which causes the nozzle to heat up quickly, as is the case when large objects are being welded or when welding is being carried out in corners and hollow places, which cause the heat to be thrown back. When the torch is dipped in the cooling vessel the gas should be shut off as, if a back-fire occurs, the flame may continue to burn in the torch, and the gas which flows out in the water may give rise to explosions, if it is ignited for any reason.

All modifications and repairs to torches should only be carried out by experienced workmen. As a rule, welders cannot be regarded

as falling in this category. If a special fitter is not available, it is preferable to have the necessary work carried out by the manufacturers.

Welding Accessories.—The *hoses,* which provide the connexion between the welding torches and the gas supply or pipes connected to it, are made of rubber and reinforced by linings or coverings of linen. Wire wrapping cannot be recommended since, if this is used, the hoses lose their flexibility. In general, all the dimensions of the hoses for oxygen and combustible gases are standardized, and should be ordered in accordance with German Industrial Standard 1901. The same Standard applies to sockets for hoses which have been standardized under Standards 1902 and 1903. The ends of the hose are drawn over the sockets and fixed with clamps. When leaks at connexions are being looked for, this should be done by brushing them over with soapy water. The hoses should be tested every month by a pressure test with compressed air or water. As a rule leaking hoses are the cause of setting the hose on fire.

During working, care should be taken not to let the hoses lie on the ground where they may be damaged by people stepping on them or riding over them. They should also be laid where they cannot be set on fire by incandescent pieces of metal which may flow or drop on them.

Fixed Gas Mains are used in permanent plants to feed the gas, and also in some cases to feed oxygen from a central station to the working benches. Instructions are given in the Supplement to the "Technical Principles of the Acetylene Association for the Construction and Erection of Acetylene Plants"* dealing with the arrangement of pipe lines for acetylene, their protection against accumulation of water and frost, the design of pipe lines and any work on gas equipment which is already in service, and this should be closely followed. Badly laid out pipe lines always result in considerable drops in pressure.

It should also be borne in mind that copper must not be used for acetylene mains since this forms an explosive compound with acetylene. Copper pipe or drawn steel pipe may be used for oxygen lines. The latter may be made with a smaller wall thickness and are cheaper in initial cost, although they have not the same length of life as copper tubes.

The mains are distinguished by painting them, and acetylene is

* Similar regulations may be obtained from the British Acetylene Association.

painted yellow, with white, and oxygen blue with yellow rings. For other gases see Standard 2403.

Goggles are the most important protective equipment for the welder. For fusion-gas welding they should protect him against heat and dazzling light rays.* There are goggles in which the glass is blue or red or green or yellow or grey, but the yellow-green variety has proved the most satisfactory. The most important thing, however, is the chemical composition of the glass. Goggles of the spectacle variety are frequently preferred because they need not be taken off during interruptions in welding. Just as frequently, however, they are objected to. In any case, goggles should not be made of heat-conducting material, where they touch the skin on the face.

When large quantities of heat are to be dealt with, it is necessary to have *asbestos gloves*, *asbestos masks* with sight glasses and *asbestos aprons* in order to protect the welder and these should also protect him against flying sparks.

Respirators which cover the nose and mouth provide protection against the breathing of poisonous gases and vapours which are set up in the welding of zinc, lead, bronze and brass. In such cases, however, it is also necessary to provide a suitable suction fan, on the welding bench.

If it is always possible to bring articles which have to be welded in large quantities to one place, it is advisable to equip a specially closed-in building as a welding workshop. The building should be as tall as possible, airy and light, but kept free from sun in order to protect the eyes. The welding benches should be so arranged that the welder can sit on a stool and have his welding work comfortably before him. It is preferable to provide equipment above the welding benches to take away gases and vapours. A fitting on which the torch may be hung and a water container for cooling the torch should be provided on the bench. All pipes should be brought to the welding bench from above. The welding workshop should have sufficient room to allow large articles which cannot be put on the welding bench to be set up, and these should be set up on blocks so that the welder need not bend over or kneel down in order to carry out his work.

* Kantner ' Goggles for welding work ", *Autogene Metallbearbeitung*, Vol. 22 (1929), p. 153.

(*b*) ARC WELDING

The Arc

Whilst the flame which is produced by the combustion of a gas with oxygen serves as a source of heat in fusion-gas welding to melt the parts of the article and the welding rod, in arc welding this source of heat is the electric arc. The term " arc " has been taken from illuminating technology, where the purpose of the arc was to provide illumination, whilst the generation of heat was regarded as an unavoidable complement. In welding with the arc the position is reversed. Here the heat is employed and the illuminating effect is a source of trouble which cannot, however, be avoided.

For welding purposes the arc may be drawn between carbon and carbon, carbon and metal, or metal and metal. As will be discussed at greater length later, various welding processes may be evolved from these arrangements. The arc, which is drawn between metal and metal, is the one which has attained considerable importance in welding technology. In some cases, however, the arc is struck between carbon and metal or between two tungsten electrodes. In the first two cases, the article, which is to be welded, forms one of the electrodes, whilst the other is formed with a carbon rod or metal wire which is melted down.

A flow of current is set up by striking the material with a welding rod or carbon electrode, and this results in the heating of the cathode and the ionization of the air space which, according to the electron theory, is necessary to maintain the arc. It is also possible to strike an arc without contact between the welding rod and the article, but a high voltage is necessary for this, and it can only be achieved in practice with high-frequency currents.

The *Temperature Conditions* in the arc have only been meagrely investigated. Measurements which may be made with the aid of a pyrometer offer great difficulties. Measurements, which are known at the present time, differ considerably from one another, and the temperatures which are set up during welding with metal electrodes have not definitely been determined. The values which have been obtained vary between 5400° F. and 6800° F. (3000° C. and 3800° C.). With direct current the temperature drop from positive to negative amounts to about 750° F. (400° C.).

The most brightly illuminated portion of an arc occurs at the

end of the electrode. Three zones in the air space should be distinguished from one another. In the middle there is a violet illuminated cone surrounded by a darker fringe, and both these are surrounded by a bright yellow illuminated misty mass of gas, the aureole, in which the small particles of the electrode, which are thrown out, burn in the air. The arc also contains in large quantities, invisible rays, the so-called ultra-violet and infra-red rays, which are extraordinarily dangerous for organic tissue and the eyes, so that special protective devices have to be adopted for the parts which may be subjected to danger.

In early days, direct current was exclusively used for arc welding, but recently alternating current has been used and this is cheaper, although it is more difficult for the welder to maintain the arc.

A direct current arc develops its maximum heat at the positive electrode, since the current has to overcome a greater resistance on exit. As a rule, this is employed in welding by attaching the positive electrode to the article since it can conduct more heat than the light welding rod (negative pole welding). The opposite procedure is adopted with thin plates since the position is reversed. In special cases, satisfactory welding is only possible when the positive pole is connected to the welding rod (positive pole welding).

In the alternating current arc on an average equal quantities of heat are produced at both electrodes, since these change their polarity many times per second, and the production of heat is distributed equally between cathode and anode. Alternating current is, therefore, at a disadvantage in this respect as compared with direct current, and this point will be shown more clearly later.

It has been proved that a higher voltage is necessary to strike the arc than to maintain it during welding, the so-called striking voltage, whereas conversely the current strength increases. There is a definite voltage corresponding to every value of current strength in the arc. If the associated relationship between current strength and voltage is plotted on a system of co-ordinates with the horizontal axis (abscissa) as the current strength and the vertical axis (ordinate) as the voltage, a curve is obtained which shows the electrical character of the arc, and is hence termed *The Arc Characteristic*. Previously it was only possible to determine satisfactorily the characteristic of a pure carbon arc. From experience gained during welding, however, it may be safely assumed that characteristics for arcs between carbon and metal and for pure metallic arcs are similar.

When a flow of current first takes place there is a maximum

value of the voltage, the peak value; afterwards there is a gradual decrease in the voltage with increasing current. During this period there is a regular burning away of the electrode. If the voltage has reached a definite critical point, however, it falls rapidly. With a slight rise in current, the arc becomes unstable and begins to jump about until finally, in a third period, in which the voltage does not alter appreciably, it begins to hiss and sizzle, which is an indication to the welder that he must reduce his current, since the current strength is too high and the arc is overloaded.

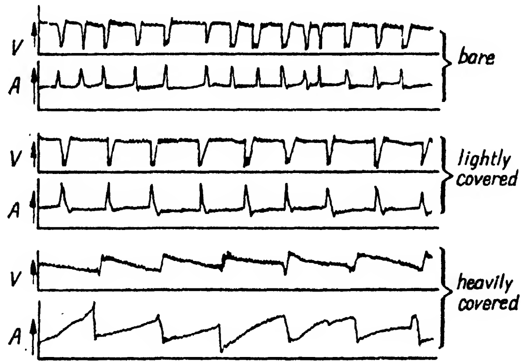
Therefore, welding may only be carried out in the stable zone. In welding with a metallic arc, however, the welding voltage automatically adjusts itself. Depending on the size of the welding wire which is used, and the most suitable current strength for it, which is adjusted according to how the arc is struck, a voltage of about 15 to 25 volts is necessary, and in special cases from 45 to 65, whereas in welding with an arc from carbon to metal about 45 to 65 volts are required.

As will be clear from what has been previously stated, it is important in welding technology for the arc to have a so-called drooping characteristic, and the supply of current must be adjusted to these conditions as will be discussed later.

It has been further shown in welding with the metallic arc that definite currents and voltage strengths invariably give the best results in the quality of a welded joint. It has been correctly assumed that these are due to the conditions existing in the arc during the transfer of the metal. It was, therefore, of considerable scientific importance to clear up the way in which this transfer of metal takes place. It had first to be established whether the transfer of iron took place in large or small drops or as a kind of mist or in the gaseous state. For a long time opinions were very vague about this matter. One view was always held more generally than any other, namely that the transfer took place in drops, and this has been confirmed by recent investigations.

The first proof was afforded by pictures of the welding process provided by the oscillograph which made it possible to register on a film the variations in voltage and current during welding, as a function of the time. Figs. 37–39 show oscillograph records of this kind. The upper curve shows the variations in voltage and the lower curve the variations in current. It may be clearly seen that at first an oscillating voltage, which is practically constant, exists in the arc, and that over a period the arc voltage gradually sinks and then

suddenly falls almost to zero, resulting in a sort of short circuit which is shown by the simultaneous increase in the current. Just as quickly the voltage rises again to the welding voltage. The process is repeated in more or less regular periods of time. It could, therefore, be assumed that at first a molten, bubbling drop is formed at the



Figs. 37–39.—Oscillograms for electrodes

end of the electrode which gradually approaches the article, so that the distance between them is decreased and the welding voltage is diminished. Further, it could be concluded that the drop is then transferred to the work, and thereby a short circuit is set up which was indicated in the oscillogram. Then the drop suddenly breaks, causing the formation of an air space and the arc is formed once more and the process is repeated.

In this respect, it is interesting to note that the process is delayed when covered electrodes are used, as is shown in figs. 38 and 39.

At the same time, it was not satisfactorily established by means of the oscillograph, whether this hypothesis definitely applies. The reduction in voltage and the short circuits could equally be due to, and could be explained by, other causes, such as the bubbling over of the molten bath and the unintentional contact between the electrode and the article due to the unsteadiness of the welder's hand.

A perfectly clear picture of the processes in the arc was first obtained when, after great difficulties, success was achieved in photographing the arc during the electric processes and registering these processes on a cinema film.

It was due to the success of the investigations of Thun and Hilpert that a photographic reproduction of the welding process

was obtained, which satisfied all requirements and gave a perfectly clear picture of the process. In addition, it provided a series of new discoveries, which have become highly important for the further development of welding technology.*

Intense illumination of the arc, which previously made it impossible to recognize what processes were going on within it, was countered by the use of a subsidiary source of light, which illuminated the welding arc and nullified the aureole and rendered the iron vapour invisible. The metal which was being transferred was thrown on a bright background as a silhouette and stood up clearly on the strips of film. By the success in obtaining exposure periods of 1/150,000 of a second up to 1200 pictures per second, which could be shown at an increased exposure speed of 120 times, so that an observation period of 2 minutes was given for processes which took place within 1 second, it was possible to follow these processes with considerable accuracy. It was shown that the transfer of iron actually took place in large or small drops which frequently required a period of transfer of only 1/2000 of a second.

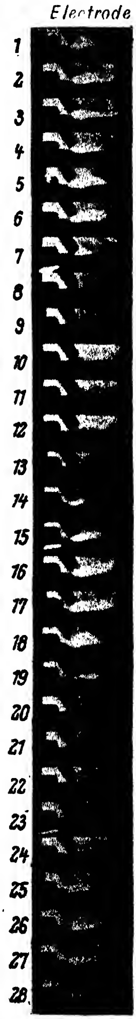


Fig. 40.—Transfer of drops in the arc

Fig. 40 shows, in 28 separate pictures, a portion of film strip which indicates clearly the transfer of two drops. The portion which lies between two pictures is the raised portion of the article shown as a silhouette. In addition the electrode which is sloping from left to right is visible as a silhouette. The dark surface which may be seen to the left of this is caused by the guide clips on the film and should not be allowed to mislead the reader.

In pictures 1 to 7, the arc, which is being blown to the right, may be seen. In pictures 8 to 11 it may be seen that a drop has formed on the electrode, which bridges the gap between itself and the article. In pictures 12 and 13, the drop has parted and in picture 14 the arc has once more begun to form. Pictures 15 to 19 show the arc once more, pictures 20 to 24 the second transfer of a drop, and pictures 25 to 28 the new arc which is formed.

* The Free Communications of the Technical Committee for Welding Technology of the Association of German Engineers (1928), No. 9.

In addition, it was established that two types of drops are formed which differ fundamentally from one another, namely, the thread-shaped form of material transfer and the mushroom-shaped form. In the former case, the end of the welding rod shows no thickening. Molten material is drawn towards the article being welded and, in this instance, capillary forces would appear to play some part. In the second case, the end of the welding rod experiences a thickening effect. It would appear that this possesses a very high temperature. In contrast to the thread form of material transfer, capillary forces between the article and the electrode would appear to be of negligible importance in this case compared with the surface voltage. The thickened portion is transferred in the shape of a mushroom. When the article is agitated vigorously the mushroom may approach very close to it, without, however, being transferred to it. Only after a relatively long period does the transfer take place. Hence two cases are to be distinguished. In one case a series of threads is formed, and the mushroom is transferred as a wide stream and the material transferred, therefore, assumes a threadlike form; in the second the mushroom separates from the electrode as a whole, passes to the article and remains on it as a spherical-shaped drop, without resulting in any junction between the article and the electrode.

These differing types of transfer are doubtless due to the current conditions and the kinds of wire. Photographs which were taken under various conditions indicated how the most favourable are to be arrived at.

By means of simultaneous investigation with the slow-motion camera and by comparing oscillograph records with the film, a method is, therefore, available, for determining the time ratio between the duration of the arc and the duration of the drops, and also for determining the number of drops, both depending on the current strength and the voltage. By this means it was established that the most favourable time ratio and the maximum number of drops was attained with a current strength of 180 amperes and a voltage of 18 volts.

Up to quite recently there had been no explanation of the phenomenon why, with normal mild and bare steel wire, molten drops of filler metal always took the path from the negative to the positive pole, whereas with high carbon, hard wires and also with many alloyed or covered wires, they preferred the path from the positive to the negative pole, i.e. in the reverse direction. Since it was usual to connect the welding wire to the negative pole and to

connect the article, which was more difficult to melt, to the hotter positive pole, it was usually assumed that the molten metal was always attracted to the article because it was drawn towards it by the preponderating surface voltage of the latter. Even more inexplicable was the behaviour of high carbon wire.

With reference to this matter, an explanation has recently been put forward from the work done by a German investigator.* The electron theory teaches us that both poles emit electrons which arrive at the opposite poles at high velocity where they convert their kinetic energy into heat. The fact that the temperature at the positive pole is considerably higher proves that the energy of negative electrons is considerably higher than the positive; consequently the stream of electrons moves in one direction from the negative to the positive pole. Hence it may be concluded that the stream of electrons bears the drops along with it and leads them to the positive pole. In this way also the phenomenon that satisfactory overhead welding can only be obtained when the electrode is connected to the negative pole, is explained. The stream of electrons conveys the molten material upwards, even against gravity. Strelow therefore assumes that when welding with alternating current this driving force always occurs when the electrode is negative.

It has been shown, moreover, that certain material compounds in or upon the electrode strengthen the electron stream and, conversely, other compounds weaken its effect. Iron oxide belongs to the former and carbon to the latter. It is well known from the arc lamp that carbon always passes from the positive to the negative pole. The positive carbon burns almost twice as quickly as the negative. The property of carbon monoxide to facilitate the exit of electrons from the negative pole has, therefore, led unintentionally to the covering of wires so as to add this material, a matter which will be discussed later. Up to the present, the advantage that the arc was easier to maintain with covered electrodes than with bare electrodes was based on the fact that the gas shield from the vapourized covering protected the arc. From what has been said, a new explanation is forthcoming, namely, that the arc is easier to strike and more stably maintained by the presence of iron oxides and various other materials.

On the other hand it has been shown by photographs of the arc that the drops roll off the electrode and are only ejected with diffi-

* Dr. Strelow, "Processes in the Electric Arc and their Influence on Welding with bare and covered electrodes", *Die Elektroschweissung* (1932), Vol. 5, p. 81.

culty when the electrode has a high carbon content and is connected to the negative pole. Hence the difficulties of welding with high carbon electrodes at the negative pole and their behaviour, as contrasted with electrodes of mild steel, may be thus explained.

Welding Machines and their Accessories

The electric current for lighting and power purposes is produced from a dynamo and usually conducted to the points of consumption by means of a system of mains. Since these mains are usually at a voltage of 220, 380 and 440, and since in welding with the arc voltages higher than 15 to 25 volts can seldom be used, the current for welding purposes cannot be directly taken from the power mains. The high mains voltage must, therefore, be reduced to the lower welding voltage.

The simplest means for achieving this end, practised during the early days of arc welding, was to couple resistances in the welding circuit in order to drop the excess voltage by converting it into heat. This method, however, possesses important technical and economic disadvantages which will be discussed in detail. In order to reduce the mains voltage to the welding voltage, direct current converters or single-phase alternating current transformers are employed nowadays, depending on whether welding is being done with direct current or alternating current. At the same time these converters and transformers must be made different from those which are used for lighting and power purposes, if they are to be used for welding, since the two sets of conditions under which the electric current is used differ essentially from one another.

In ordinary work one is concerned with maintaining a current at constant voltage. Fluctuations in current not only affect working very considerably, but have a harmful effect on the machine which is producing the current and lead to its rapid deterioration. Short circuits are especially dangerous, since they may result in an extraordinarily high increase in the current strength, where a current is supplied at a constant voltage. In order to guard against this dangerous result fuses are put in to power and lighting mains which break the current if this rises to a dangerous limit.

In welding, however, short circuits cannot be avoided, and they are an essential part of the welding process. Even when the arc is struck a short circuit is set up on account of the contact between the electrode and the article. Further short circuits occur every time

a drop is transferred from the electrode to the article. Therefore, current supplies at constant voltage cannot be used. The first condition which has therefore to be fulfilled by a supply of current which is to be suitable for welding purposes is that it must be able to withstand any short circuit current which may occur. Modern welding generators have usually to carry high short-circuit currents. At the same time it is necessary to confine the short-circuit current within definite limits in order to avoid damaging the machine. In other words, in order to prevent the electrode and the article from fusing together and solidifying on contact, it is necessary that *the short circuit current shall be limited to a suitable amount when contact occurs between the electrode and the article, as well as when a drop is transferred.*

This is only possible when the voltage which is set up at the moment when the total arc resistance consists only of the low contact resistance between the electrode material and the article, falls well below the welding voltage.

On the other hand, a higher voltage is necessary both for striking the arc, when the resistance of the air space has to be broken down, and also for maintaining the arc. Since it is formed by the ionization of the air space, the striking voltage must be higher than the welding voltage.

In most welding generators the striking voltage is equal to the open circuit voltage, which is made slightly greater in order to overcome the voltage drop in the mains and any resistance in the accessories. Only in the most modern machines is the striking voltage independent of the open circuit voltage.

It is not advisable to select too high an open circuit voltage. It is better to limit it so that too long an arc cannot be drawn, as with an increase in arc length the absorption of atmospheric oxygen and nitrogen into the weld increases and the weld is thereby spoiled. In no case must the open circuit voltage of the current supply be so high that it constitutes a danger to the welder. Since the work is connected to earth, the welder may be subjected to the full voltage if, by any chance, he touches the electrode. Therefore with direct current, the open circuit voltage should not exceed 100 volts, and with alternating current it should not exceed 75 volts. Unnecessarily high open circuit voltages necessitate having large machines and make these uneconomical.

A second condition for a current supply which is to be suitable for welding may therefore be written down: " The striking voltage

of the current supply must be such that the arc may be easily struck but the welding voltage must not exceed practical permissible limits."

From what has been said it is necessary that the arc as well as the current supply should have drooping static characteristics, since when the arc is struck the voltage should be higher than the welding voltage, and on the other hand when contact is made between the electrode and the article, the voltage should be lower than the welding voltage.

This requirement does not exhaust all those which have to be laid

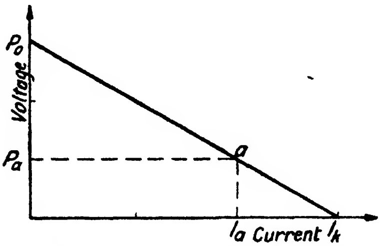


Fig. 41.—Current supply characteristic

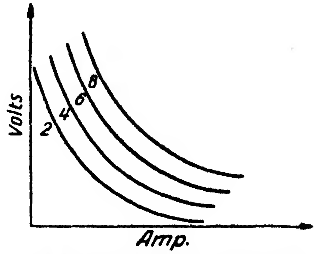


Fig. 42.—Carbon arc characteristics for various arc lengths

down for a current supply which is to be suitable for welding purposes.

If the welding process is to proceed with regularity, as is necessary if a clean weld seam is to be obtained, the arc should not be extinguished if the distance of the electrode from the article, and hence the length of the arc, varies within definite limits. It is impossible even for the most skilled welder to guide his electrode so uniformly that this state of affairs can always be avoided. The current supply must therefore accommodate itself to the variations in arc length and at the same time to the variations in voltage and current strength. We say that the arc must be elastic.

The third requirement, therefore, for a current supply which is to be suitable for welding is as follows: "The arc should be so elastic that it is not extinguished when its length is varied within definite limits."

The following remarks will indicate how this condition can be fulfilled.

Fig. 41 shows the characteristic of a current supply in its most simple form as a straight line which satisfies the requirements that the arc energy is constant, and this, from a law of electric-currents, is equal to E × I. It is equal to the product of the voltage and the current. The value P_o is the so-called open circuit or striking vol-

tage. The value I_k is the short-circuit current. During welding one works at the point *a*. From what has previously been said, the striking voltage should be greater than the arc voltage during welding. The short-circuit voltage on the other hand should be limited. We get a high voltage peak, the striking peak, after which the voltage falls more or less rapidly, while the current strength increases to a definite value as soon as the voltage has reached zero.

By combining the current characteristic with that of the arc it can now be determined whether the current supply guarantees an elastic arc. This characteristic varies according to the arc length. Fig. 42 shows a series of such characteristics for varying arc lengths. The characteristic of the current supply, as shown in fig. 41, has been

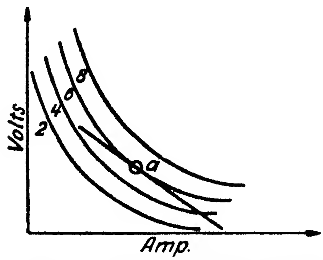


Fig. 43.—Characteristics for a carbon arc along with a superposed flat current characteristic.

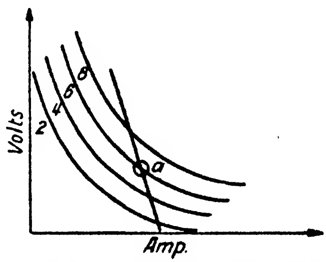


Fig. 44.—Carbon arc characteristics along with a superposed steep current characteristic.

drawn on these characteristics in figs. 43 and 44. In the first case, providing welding is done at point *a* on this curve, the current characteristic cuts the 6 mm. (0·24 in.) curve of the arc characteristic. If, when the electrode is moved, the arc length increases to 8 mm. (0·32 in.), the arc curves do not intersect, since the arc can only follow the 8 mm. (0·32 in.) characteristic, whereas the welding point must always follow the current characteristic. The result is that the arc is extinguished. It is inelastic.

If the current characteristic, however, is steeper, as is shown in fig. 44, it is possible when the arc is lengthened or shortened to get the welding point of the current characteristic to fall on the 8 mm. (0·32 in.) or 4 mm. (0·16 in.) arc characteristics respectively, since the current characteristic cuts these curves. Further, in spite of the variation in arc length the arc is not extinguished and it is elastic. Therefore the arc is more elastic the steeper the current characteristic.

In practice, the logical step of choosing the current characteristic

so steep that it cuts as many arc characteristics as possible cannot be taken because experience has shown that the depth of penetration is better the flatter the characteristic. If this condition has also to be fulfilled, the current characteristic must not be too steep. This is also desirable because losses due to spluttering can be kept within moderate limits when the characteristic of the current supply is not too steep, and on the other hand not too flat.

If the machine is to give adequate current for various work, the choice of the characteristic must be such that a definite compromise is made between a steep and flat characteristic. For special work, however, the characteristic may be so selected as to suit the purpose for which it is required.

The previous discussion has neglected the fact of whether the current supply is direct or alternating. We will therefore add the remark that, for both kinds of current, fundamentally similar forms for the characteristics of current supplies are obtained.

Current Supplies.—In arc welding, it has been shown that energy requirements with currents of 80–1000 amperes and welding voltages of 18–65 volts are necessary, the current supply having an open circuit voltage of approximately 45–100 volts. Modern cross field dynamos, in which the open circuit voltage is only 10 to 30, provide an exception. As will be shown later, welding voltages of 18–22 are the most common (welding with metallic arc and steel electrodes). In special cases, welding is carried out with current strengths of 500–1000 amperes and more, at a voltage of about 65 volts (welding with a metallic arc and cast iron electrodes) and with current strengths of 150–300 amperes at a voltage of 40–60 volts (welding with carbon electrodes).

Welding from the Mains.—Originally current was taken from the direct current mains of power stations and this current supply is one which is also used to-day with certain provisions. Since the voltage of a main of this kind is considerably higher than the voltage necessary for welding, resistances have to be coupled in, in order to reduce the mains voltage to the welding voltage. In addition, these external resistances must be adjustable, since welding will be done with various electrode diameters at various current strengths. Either wire-wound resistances made of ordinary steel or alloy wire or fluid resistances are used. Regulation is achieved in the former case by switching in or cutting out individual resistance coils, and in the latter case by varying the depth of immersion of the plates. If we examine the characteristic of the current supply in fig. 45, we see

that the external resistances, besides reducing the mains voltage, act so as to give the current source a falling characteristic and provide protection against too great an increase in the current strength during the short circuit.

The characteristics which take the form of a straight line are shown on the figure for a mains voltage of 110 volts and have been determined for two control settings. Curve *a* shows the characteristic with an external resistance designed to give a welding voltage of 20 volts and a welding current of 180 amperes. Curve *b* is for 20 volts and 100 amperes current. In both cases the short circuit current has been limited satisfactorily. In the first case, when the voltage is equal to 0 the short circuit current amounts to 220 amperes, and in the second case 120 amperes.

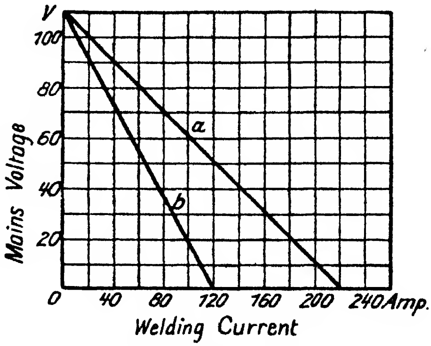


Fig. 45.—A characteristic when welding from the mains

a, Characteristic for 20-volt welding voltage and 180-amp. welding current; *b*, characteristic for 20-volt welding voltage and 100-amp. welding current.

The conditions which have to be imposed in order to attain a regular welding process are therefore fulfilled if welding is carried out by means of external resistances which are called *Smoothing Resistances*.

On the other hand, external resistances of steel wire have a disadvantage in that, during heating up, their internal resistance varies and they have frequently to be adjusted. In this respect wire-wound resistances made of alloys are better. Water resistances heat up the water to a considerable extent and decompose it with the formation of an explosive gas. Moreover, external resistances adversely affect the economics of welding to a very high degree.

To summarize: Welding from the mains with external resistances ensures a regular welding process, but it has the following disadvantages:

1. The external resistances have nearly always to be regulated.
2. The efficiency is very low because a large proportion of the electrical energy is dissipated.

The same applies when welding is carried out with ordinary constant-voltage dynamos and transformers.

For these reasons welding from the mains has been almost entirely dropped, and with few exceptions welding is carried out with special machines consisting of direct current converters or alternating current transformers. Among the former we find motor generators, which have an adequate constant voltage for striking the arc, and in which a drooping characteristic can only be attained by the provision of external resistances, and converters with generators which themselves give a drooping characteristic.

Welding transformers are also constructed so as to give drooping characteristics.

Generators with Special External Resistances.—The welding generator in this case is a compounded machine the voltage of which remains sensibly constant at all loads. The open circuit voltage usually amounts to 60 or 70 volts, so that there is a sufficiently high striking voltage and the arc may easily be struck. External resistances in the welding current circuit ensure a suitable drooping characteristic, keep the welding process uniform and ensure that the short circuit current is kept within suitable limits and that the machine voltage is simultaneously reduced below the welding voltage. The characteristic is similar to that obtained when welding from the mains but the efficiency of the machine is very much better as less voltage has to be dropped. Several welding points may be coupled to a generator of this type if the generator output is selected high enough to take care of the energy requirements and the number of points. In general, it is sufficient to reckon on a maximum output of 75 per cent of the total energy requirement for all the welding points, as seldom or never will all welding points be working at their maximum output. Experience has shown that the actual welding time at one point would amount to from 30–50 per cent of the total working time.

Generators with Drooping Characteristics.—The efficiency of a generator is most satisfactory if it supplies welding current with a drooping characteristic, since loss of time caused by adjusting the external resistances is avoided.

With generators of this kind it is naturally impossible to connect several welding points, since on short circuit the voltage falls to zero, and therefore as soon as one occurs, either intentionally or unintentionally, it is impossible to weld at the other welding points. It is therefore necessary to provide a special welding machine for each welding bench. In most cases this is not a disadvantage but an advantage. Firstly, separate welding plants can be better suited to requirements, and secondly, they may be built so as to be portable.

Wherever welding is carried out at various places the single plant is the only one possible.

Therefore, a single welding generator with a drooping characteristic—that is a machine in which any undesirable increase in current is accompanied by a corresponding reduction in voltage, and hence one in which these quantities are automatically maintained within the limits necessary for welding—is the one which has developed most rapidly, especially in Germany.

In order to achieve this end various methods are possible. A very common one is to fit opposing windings on the magnets of the generator; another is to utilize armature reaction; a third, which had made great headway in recent years, is to take the welding current from a strengthened cross field set up by armature reaction and obtained by special methods.

The way the above methods, which are used for obtaining a drooping characteristic, work is as follows:

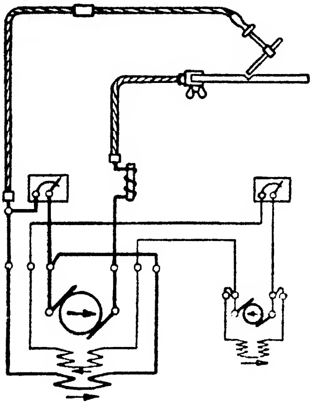
Generators with opposing Compound Windings.—These are shunt wound machines. If a second winding (a compound winding) is put on the poles in the opposite direction to the shunt winding, the former weakens the magnetic field and in certain circumstances completely neutralizes it. Moreover, if the second winding is connected to the external current circuit of the machine to form a series winding, the desired effect is obtained. The magnetic field is weakened and the voltage thereby reduced, every time the current increases.

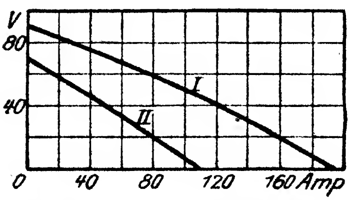
A shunt winding, which is excited by the machine itself, loses its magnetism almost entirely when the armature current is short circuited, since the voltage then falls to zero and consequently self excitation is virtually reduced to zero. After a short circuit, therefore, the voltage only rises slowly, and a certain amount of time elapses before the necessary striking voltage is available for striking the arc again. For this reason, with welding generators of this type, a separately excited magnetic winding is generally used in place of a self-excited shunt winding, since the former retains its magnetism during a short circuit and when this is finished supplies the armature again with voltage.

Generators with Armature Reaction.—The effect of armature reaction depends on the fact that when an armature consisting of an iron core with a wire winding is rotated so as to produce a current in the winding of the armature, a second magnetic field is formed in the main field of the electro magnets, which weakens and distorts

the main field to a greater or less extent. The main field is weakened by one which opposes it, and distortion is set up by a field perpendicular to the main field. The combination of both of these fields forms the armature field. By suitably proportioning the opposing and cross windings and the magnetic properties of the armature itself, the armature reaction on the main field can be designed, so that when a definite current is exceeded the armature field acts as a throttle, and the voltage finally falls to zero. Because of the reduction in voltage, the current cannot rise to any appreciable extent. In this way a drooping characteristic is obtained.

*Cross Field Generators.**—These are self-exciting, self-regulating direct current dynamos in which the armature field, which is perpendicular to the main field, as has been mentioned in all the generators which have previously been described, itself provides the necessary current for welding without any auxiliary means. The main field itself is short circuited. This cross field produces a second armature field, displaced at 90° to the direction of rotation, and this directly opposes the original exciting main field and weakens it. According to the external load conditions, an internal state of equilibrium between the current strength and the corresponding voltage is immediately and automatically set up, in such a way that the resultant field, that is the main field minus the armature reaction of the working current, produces a corresponding assisting current, the cross field of which, in its turn, induces the correct working voltage.





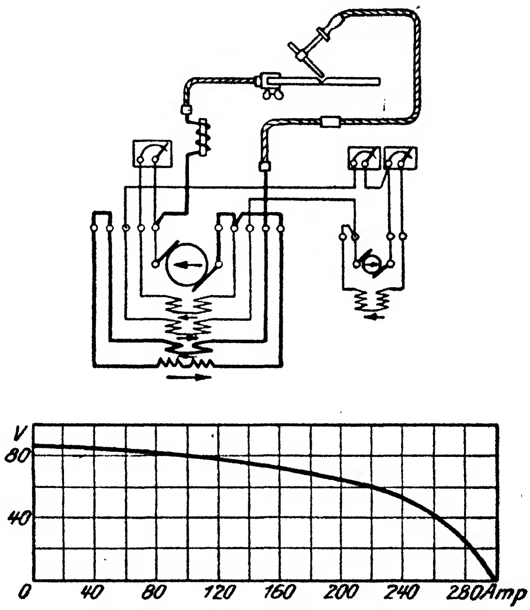
Figs. 46 and 47.—Wiring diagram and characteristic of a welding generator with opposing compound windings and separate excitation.

In order to control the primary exciting field within the agreed limits, so that the generator may be regulated to give the desired current, there are various possible methods which will be discussed in greater detail later.

* Rosenberg, *The Direct Current Cross Field Machine* (J. Springer, 1928, Berlin).

The following figures show the *Wiring Diagrams* and *Characteristics* of some well-known welding generators. According to whether the generator is constructed as a self-excited, automatically-excited, or separately-excited machine, there are a large number of different designs which depend for their working on opposing compound windings or armature reaction. On the other hand, cross field generators are always self-excited machines. It must not be assumed that the selection which has been made of the various types indicates that other machines which have not been mentioned here are inferior in quality.

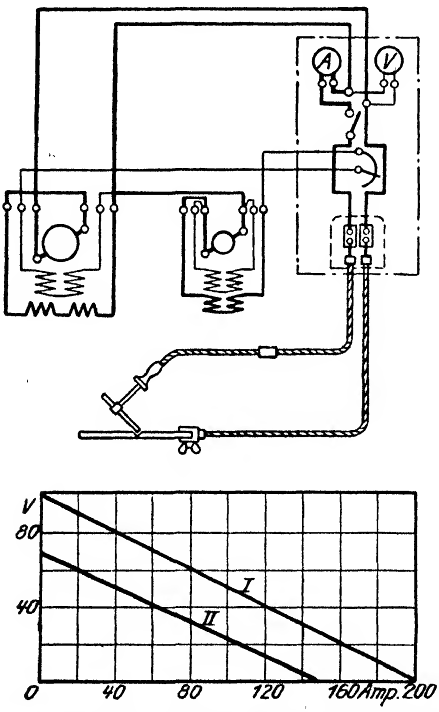
Figs. 46 and 47 show the wiring diagram, and below, the characteristic of a generator having an opposing compound winding and separate excitation, and without further comment the generator will be clearly understood from what has been previously mentioned. The open circuit voltage is fixed by means of a control in the shunt circuit, and the desired welding current by a controller in parallel with the series winding. A choke coil is coupled in to the welding current circuit. The characteristics of the machine which are shown under the wiring diagram for two regulator settings has a fairly flat form. In spite of this, welding may be carried out quite satisfactorily with this machine, as the characteristic is otherwise quite satisfactory, though not to the same extent as other welding generators.



Figs. 48 and 49.—Wiring diagram and characteristic of a welding generator with an opposing compound winding, self and separate excitation.

Figs. 48 and 49 show the wiring of a generator with opposing compound windings, which is both self excited and separately excited, and below it is shown the characteristic of the machine. This wiring is known as the "*Krämer*" wiring. In addition to the

opposing compound winding and the independent excitation winding, there is a shunt winding which is self-excited. A choke coil is also coupled in the welding current circuit. The self-excited winding has the effect of making the characteristic fall more steeply within the voltage of 15–25 volts, which is necessary for welding, and this is shown in the characteristic which has been drawn under the wiring diagram. Consequently the current strength remains almost constant within these limits. Control of the characteristic is achieved by means of three regulators which are coupled in the self-excited and separately excited fields of the exciting machine, and also in the shunt winding. The fourth winding which is seen in the wiring diagram of the welding generator is the interpole winding, the function of which it is to prevent the formation of sparks at the commutator. In such a case the inter poles are arranged perpendicular to the main poles so that they form a field which opposes the armature cross field, which causes the formation of sparks, and this weakens the cross field.



Figs. 50 and 51.—Wiring diagram and characteristic of a welding generator with armature reaction and separate excitation.

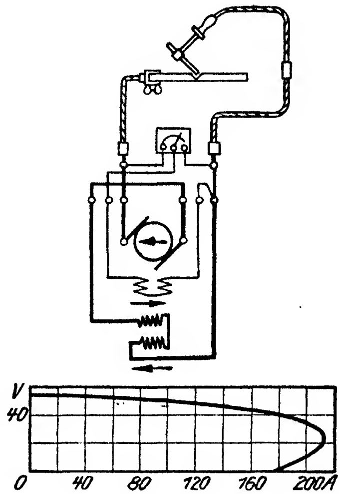
Figs. 50 and 51 show the wiring diagram and characteristic of a generator with armature reaction and separate excitation. The exciting machine is a compound machine having shunt and series windings. As before, we notice that the welding generator is provided with two windings. The upper one, which is shown in thin lines, is the shunt winding, and the lower one, which is indicated as a thick line, is an inter pole winding. In this machine, however, the inter poles are not connected as in the previously described machine, so as to weaken the armature field, but so as to strengthen this field, and hence set up armature reaction which has

the effect of causing the drooping characteristic, described on p. 72. The welding current strength is controlled by means of a regulator which is coupled into the shunt circuit of the welding generator.

The characteristic of the machine, which is maintained within practical permissible limits, is shown for two regulator settings under the wiring diagram.

There are modifications to the generators which have been described, but these will not be discussed further. Among these are machines with combined self and separate excitation and machines with armature reaction, separate excitation and self excitation.

In addition, figs. 52 and 53 show the wiring diagram and characteristic of a generator which works only with self excitation and differs entirely from all other machines. In order to overcome the disadvantage which machines of this type have, as we have already seen, namely, that the voltage after a short circuit only rises again very gradually, a so-called damping winding has been provided in this machine, and this surrounds the pole shoes of the main poles. When a short circuit occurs, the damping winding sets up a high induction current which strengthens and maintains the main field so that the full voltage is available during the time which is necessary for striking the arc. In these machines regulation is obtained by means of the shunt winding. On account of their simplicity these machines are cheaper than separately excited ones. At high current strengths the characteristic possesses a peculiar shape and the curve is bent backwards. The low open circuit voltage compels the welder to keep a short arc.

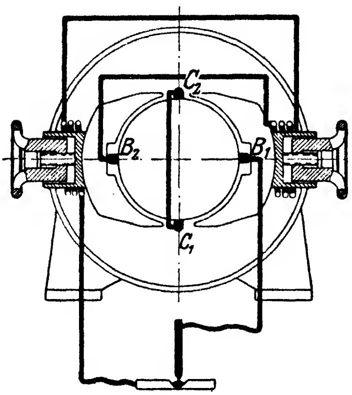


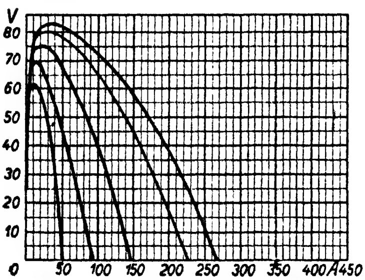
Figs. 52 and 53.—Wiring diagram and characteristic of a welding generator with self-excitation.

Figs. 54 and 55 show the wiring and characteristic of the cross field *dynamo* which has been patented and put on the market by Rosenberg. The main current is short circuited between the brushes C_1, C_2. The working current is taken from the cross field between the brushes B_1 and B_2. Regulation is obtained by turning the handwheels, which are provided with steel pads and which are moved

backwards and forwards along a screwed spindle inside the hollow pole casings. By this means the poles are more or less filled with iron and their magnetic reluctance is adjusted to suit the required conditions. If the primary field is weakened an equilibrium condition will be set up, as has been previously mentioned, since a correspondingly reduced working current is generated.

The characteristics for various current strengths which have been drawn underneath the wiring diagram, show an extraordinarily steep slope. In consequence the arc is very elastic and permits of very smooth welding, although the danger exists that too long an arc may be drawn. Machines of this type should only be handed over to experienced welders in whose hands they will deliver excellent work. It should be mentioned further that there are cross field dynamos in which the weakening or strengthening of the magnetic field is obtained by two opposing windings which are fitted on the poles, the resistance of which may be changed by means of a special wiring arrangement.





Figs. 54 and 55.—Wiring diagram and characteristic of a cross-field welding generator, Elin construction.

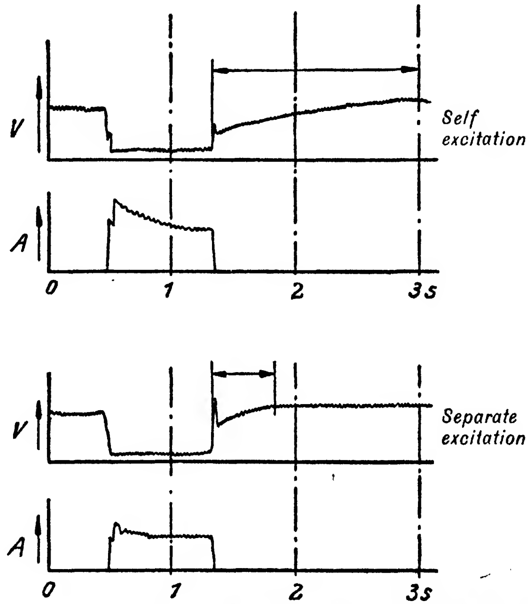
C_1 C_2, Main current brushes;
B_1 B_2, cross-field brushes.

It is worth noting that in cross field dynamos the open circuit voltage has no effect on the magnitude of the welding current. It is also unaffected by the regulator since it only depends on the greater or less remnant magnetism in the machine. Consequently cross field dynamos have the advantage, which should not be underestimated, of possessing an extremely low open circuit voltage which lies between 10 and 30 volts.

Dynamic Characteristics of Generators.—In the previous pages welding generators have only been judged on their suitability for welding purposes by means of their static characteristics, that is, by curves which have been obtained at stable loads under

steady conditions. It has been shown from practice, however, that this method does not provide satisfactory evidence of the suitability of a welding machine in every case. Frequently it so happens that two machines having the same static characteristic, behave very differently during welding. In order to judge a machine, therefore, one must also examine its dynamic characteristic, i.e. the curve which shows the relationship between voltage, current and time, and which shows the behaviour of various machines subjected to rapidly varying loads.* These characteristics may be obtained by means of a measuring system having a high natural frequency, and with the help of oscillographs which indicate variations in current and voltage on a moving strip of film.

A self-excited and separately excited machine have been chosen as an example of two machines which have the same static characteristic but which behave differently during welding. It has already been mentioned that the voltage only rises very slowly again after a short circuit with the former type, since the magnetic winding loses its magnetism almost completely, while with the latter type the winding retains its magnetism and provides the armature with the necessary voltage.



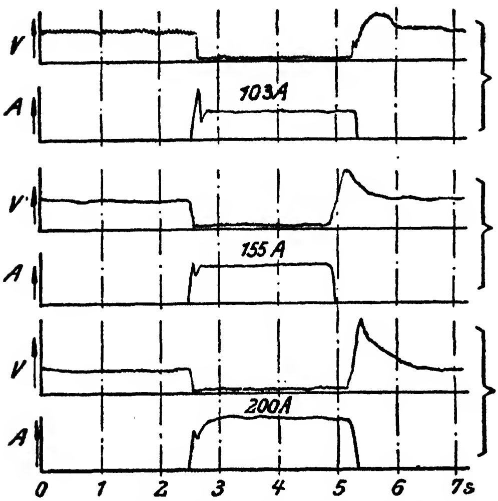
Figs. 56 and 57.—Oscillograms of a self-excited welding generator (fig. 56) and a separately excited welding generator (fig. 57).

The static characteristic is no guide to this phenomenon, whereas the dynamic characteristic shows it very clearly, as may be seen from figs. 56 and 57. The slow building up of the voltage after a short circuit in the self-excited machine may be clearly seen,

* Bung, " Tests with oscillographs for the investigation of the processes in the Electric Welding Arc ", *Elektrotechnik u. Maschinenbau*, Vol. 26 (1928), p. 2.

as well as the rapid return which is achieved by the separately excited machine.

Figs. 58 to 60 show what happens at various positions of the regulator with the cross field dynamo which has been described. It is worth while noting the peak current, which is set up when a short circuit occurs, but which is continually reduced, the higher the short circuit current, and at 200 amperes is even reduced below the steady working current. In addition, the fluctuation of the current may be seen which persists until the peak current reaches the steady working current. This is due to the opposing influences of the main field and the cross field. The characteristics also show a rapid rise of voltage after the short circuit is finished.

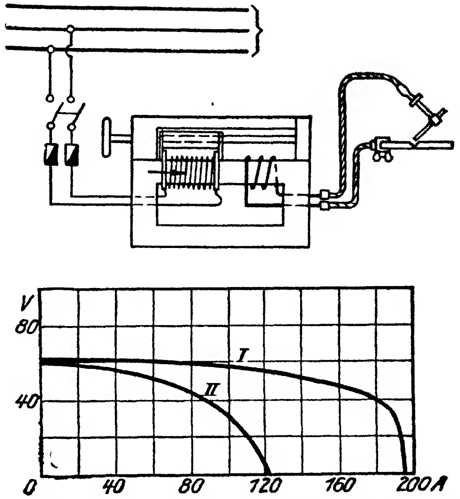


Figs. 58–60.—Oscillograms of a cross-field welding generator for various current strengths

Welding Transformers.—Alternating current transformers of the ordinary type maintain the voltage constant at varying current loads just as do ordinary type direct current generators, and consequently they are just as unsuitable as the latter for welding purposes. In this respect, in order that they should fulfil the requirements which must be demanded of them, they have to be specially constructed. The aim of giving the transformer a drooping characteristic is achieved with the help of magnetic dispersion, provided one does not wish to revert to the use of external coils in the welding current circuit and thereby drop the voltage and reduce the output. Dispersion is understood to mean that portion of the lines of force which is generated in the primary winding and which is not allowed to cut the secondary winding. The greater the number of these lines of force, the greater is the dispersion in the transformer, and hence the greater will be the voltage drop and the more suitable will be the transformer for welding.

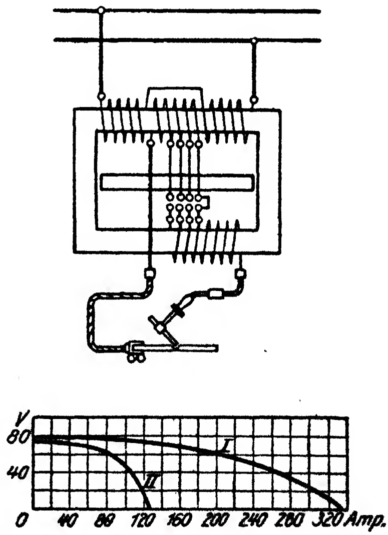
Regulation of the current strength may be obtained by the

switching in or out of secondary or primary turns. The most important thing is to vary the ratio between the number of primary and secondary turns. It is frequently more satisfactory to restrict regulation to the primary windings (Tapping Regulation) because here the wire is not so thick, and it is mechanically a simpler matter, and moreover the secondary winding often has so few turns that the switching in or out of one turn is too much.



Figs. 61 and 62.—Wiring diagram and characteristic of an alternating-current transformer with dispersion control (movable coil).

Fig. 61 shows the layout of a transformer in which use is made of magnetic dispersion. The secondary winding may be pushed towards the primary winding by means of a handwheel. The nearer the windings approach one another, the less will be the dispersion. The characteristic which is shown in fig. 62 for the two limit settings of the secondary windings gives a satisfactory curve. Curve 1 gives the characteristic for minimum dispersion and Curve 2 the characteristic for maximum dispersion.



Figs. 63 and 64.—Wiring diagram and characteristic of a welding transformer with a dispersion core.

Fig. 63 shows the layout of a transformer in which regulation is also achieved by varying the dispersion, but in another way, namely, by means of so-called core dispersion. The primary and secondary windings are split. The two parts of the primary winding are fixed on one leg of the transformer core, and between them is arranged one part of the

As a rule, the welding set is driven by means of a motor which is built with the generator. Welding sets are very seldom belt driven. When work has to be carried out in places where there is no power available for driving purposes, the welding generator may be driven by means of a petrol motor and the plant is, therefore, made portable.

If several welding points are required close to one another, the cost of the welding plant may be reduced by assembling a powerful motor having several welding generators on one shaft. The advantage, however, is inconsiderable, unless all the welding points which are coupled together are continuously working, as otherwise there are high open circuit losses. In addition to this, there is the danger that if the motor is damaged, not only one, but several welding points will be put out of commission. An arrangement of this type can only be used for mass production work in which welding is carried on continuously. Even in these circumstances it is inadvisable, with permanent installations, to couple more than two to four generators on one motor.

Welding Accessories.—In addition to the welding machine or other source of current there is in arc welding also, a series of auxiliary equipment which belong to the welding plant. We discussed some of them when dealing with the wiring diagrams, namely, the regulators, which are required for each plant, and also the external resistances and choke coils which are required for various plants. In addition to these, the following items are always necessary: measuring instruments, conductors or cables, holder for electrodes, and protective equipment.

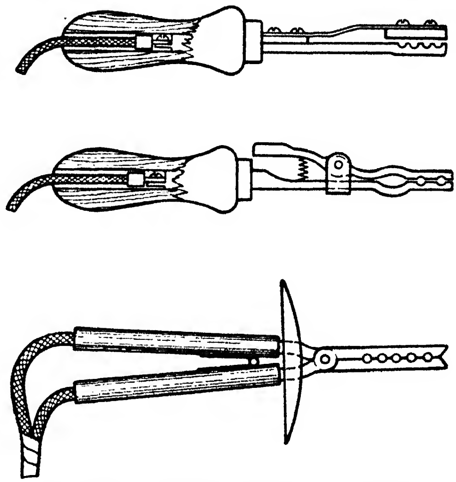
As *Measuring Instruments*, we use those which are well-known in electrical equipment, namely, the voltmeter for voltage measurements, the ammeter for current measurements and if necessary the kilowatt hour meter for determining the current which has been consumed, if this is required in order to determine the costs of welding as in piecework welding rates.

Measuring instruments, regulators, external resistances and choke coils are usually built into the welding machine, but the first are frequently fixed on a switchboard, especially in large permanent installations.

Holders for electrodes, which are called *Welding Pliers*, and which are used to hold the welding rod or welding carbon, should be light and easily handled, so that they do not hinder the welder during his work, but allow him to move the electrode with freedom. They must

also be safe during working, so that they do not endanger the welder. In addition welding pliers must allow the electrode to be changed quickly and easily.

Very simple designs fulfil these requirements, as may be seen from figs. 65–67, which show some welding pliers which are in common use. In the type shown in fig. 65 the electrode is fastened in from the side between the spring clips of copper or steel which fit against one another, so that the remaining piece of a used electrode falls out. As the springs fail after long service, the designs shown in figs. 66 and 67 are better. In these the gripping faces are pressed against one another by a special spring and in order to insert the electrode, they are opened by means of a lever. In all these pliers the connecting piece to the cable carrying the current is covered by a wooden insulated handle.



Figs. 65–67.—Welding pliers for cold welding

Light welding pliers such as those which have been described are used for electrodes of 14 gauge to 2/0 gauge, such as are used in the welding of steel. For heavy cast iron electrodes, thicker and heavier holders are necessary.

The current is usually led from the current supply to both the article and to the welding pliers by means of a cable which consists of a number of copper wires, which are twisted into a conductor, and surrounded by a stout well-wearing insulating sheath. The purpose of this is to prevent the conductor, as well as the electrode holder, from hindering the welder and therefore it must be easily moved but, at the same time, protected against damage.

The cross-section of the cable should be so dimensioned that it does not suffer from excessive heating on account of the welding current. As has been previously mentioned, the heating of the conductor depends on the current strength. By means of regulations and standards of the Association of German Electrical Engineers,

the current strength with which a definite conductor section may be loaded has been laid down. The standards for normal current strengths are as follows:

Current Strength From	Section From
150–200 amps.	·077–·110 in.^{2}
250–400 ,,	·285–·370 in.^{2}
600–800 ,,	1·360–1·65 in.^{2}

However, since the current strength during welding only reaches its maximum value for a short time, and for a period the current is completely broken, that is, the conductor is not continuously loaded, and as moreover the current strength only exceeds the welding current by a small amount during a short circuit, the conductor section may safely be loaded about 25 per cent higher. For example, a section of ·054–·077 in.^{2} is sufficient for a current strength of 150–200 amperes if the line is not too long. For longer lines account must be taken of the voltage drop in the line, and the section must be so selected that this falls within permissible limits. The voltage drop may be calculated from the formula $p = \frac{2Il}{qx}$,

where q is the cross-section in in.^{2},
I is the current strength in amperes,
l is the single length of the cable in feet,
p is the voltage drop in volts,
x is the conductivity of copper which is equal to $1{\cdot}1745 \times 10^5$.

The cable is fixed to the article by means of clamps or screw clips.

Finally, protective equipment comes in the category of welding accessories, and these should protect the welder against sparks, heat and the ultra-violet light from the arc, which is extremely dangerous for the eyes. This will be discussed in a section on "Accident Prevention".

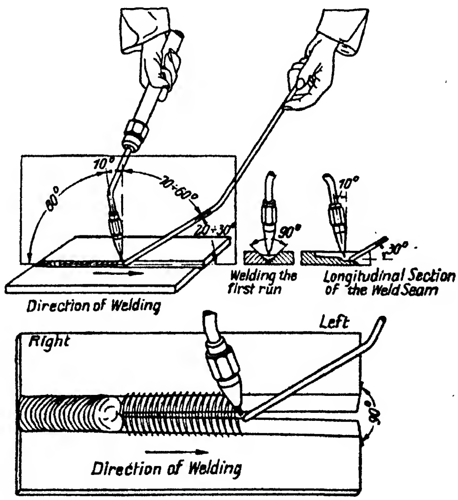
Fusion Welding Processes

(a) KINDS OF WELDING

Fusion welding is a metallurgical process. Even if, in accordance with the definition of welding, it is required that the junction zone of a welded article with the part joined to it should form as homogeneous a whole as possible, it should not be forgotten that this

condition cannot always be fulfilled, especially where the two metals which are being joined possess a rolled structure, whereas the weld zone has a cast structure, at least in its original condition. Moreover, the oxy-acetylene flame produces an effect different in many respects from that produced by the arc on the structure of the weld seam as well as on the articles being joined. Consequently the object which we are trying to attain is in some cases better achieved by fusion-gas welding and in other cases by arc welding. Both processes have their advantages, but at the same time their disadvantages, so that sometimes the one is the more suitable, sometimes the other.

The continued attempts to improve and equalize these two processes which are in competition with one another, or to make them more suitable for some special purpose, have had the result, especially in recent times, of introducing a series of new methods. Processes have even been developed in which gas and the arc are used at the same time. It is therefore necessary for both the constructor and the works engineer to know exactly the peculiarities of the various processes, and when he knows these, which of the two he should use in various circumstances. As far as quality is concerned, there are various welding processes, which, in many respects, give equally good results. In these circumstances economy would be the deciding factor, and this would differ according to the local conditions. We will discuss this matter in greater detail in a later section. At this stage we will go into the differences of the various kinds of welding more closely, and it will be shown what conclusions may be drawn from the use of each, depending on the quality of the results obtainable.

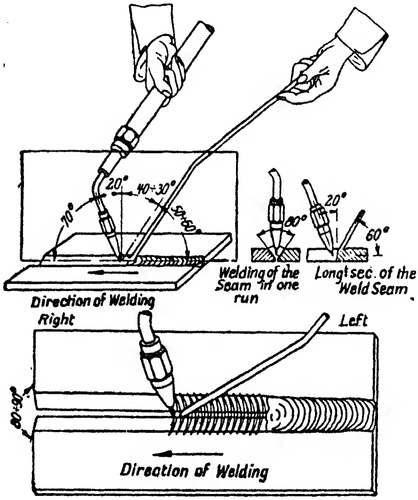


Figs 68–71.—Forward welding (left-hand welding)

Fusion-Gas Welding Process.—In oxy-acetylene welding, it was previously the rule to weld in the way which is illustrated in figs. 68 to 71. Viewed from the position of the welder, the torch was

moved along from right to left with an oscillating motion, so that both edges of the weld were rendered molten to an equal extent. The welding rod was simultaneously moved in a straight line in front of the flame. In order that the flame shall melt down the root of the Vee, it is necessary to provide a fairly wide opening when thick plates are being welded. The flame is held more or less inclined, depending on whether thin or thick plates are being welded.

In this kind of welding, a large portion of the heat is useless for the work, since the flame may spread unhindered over the surface of the plate, and this has the effect of heating the surrounding portion of the weld zone in an undesirable way and of giving rise to stresses or distortions in the plate.

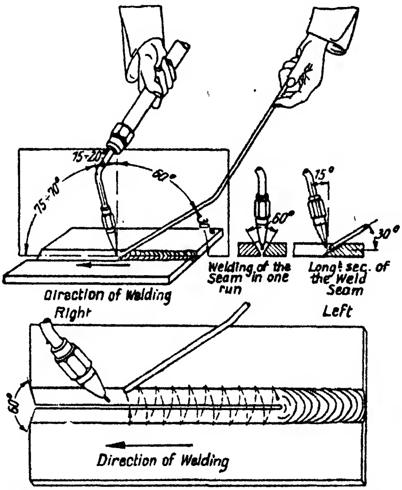


Figs. 72–75.—Backward welding (old "right" welding)

Consequently, a few years ago there was a change to welding in the opposite direction, that is, as viewed from the position of the welder, from left to right. This kind of welding is termed "right-hand welding" as opposed to the previous usual type of "left-hand welding". This notation, which has obtained a firm footing, is an unfortunate one. If the plates are arranged, not as shown in the figure, but so that the weld groove approaches the welder, or when vertical or overhead welding is being carried out on plates, we can no longer speak of right- or left-hand welding. It would be better to term left-hand welding "*Forward Welding*", since the torch is moved forward in the direction of the flame, and to term right-hand welding "*Backward Welding*", as in this case the position is reversed. This notation has, therefore, been selected for the following pages in the hope that it will be adopted.

In backward welding, the torch and the welding rod may be manipulated in the same way as they are in forward welding, figs. 72 to 75. This kind of welding was suggested by Richter years ago and he therefore terms it "classical right-hand welding". Various advantages result from it, but these are more apparent if the manipulation

of the torch and welding rod is modified and if, as is shown in figs. 76 to 79, the torch is moved in a straight line along the welding groove, as is being done more and more. The welding rod, however, is oscillated behind the torch in contact with the weld, both touching the flame. The flame is held at a rather steep angle and fairly deep into the Vee. This may be done because the flame builds up on the weld, which has already been made and therefore spreads over the upper part of the welding Vee so that there is no need to fear insufficient fusion. Because of the property of the oxy-acetylene flame, a definite distance should, of course, be maintained from the edges. In accordance with what has been said above the conical flame should fill the Vee. A cone which is too long may not melt down the edges to a sufficient extent, and this leads to loss in gas. The manipulation of the torch, which is usual for backward welding, has the advantage that the groove is rendered molten right down to the bottom, even with the thickest plates, and is also well filled so that the flame is prevented from spreading over the surface of the plate to the same extent as in forward welding. In addition, the groove is melted down much better and much more quickly, and the flame is much more satisfactorily utilized. Backward welding therefore results in savings in time and gas, and is cheaper than forward welding. As compared with forward welding, these savings are greater, as we shall see later, if an angle of Vee of 60° is selected for backward welding for all plate thicknesses. This then makes it possible to guide the torch in a straight line, whereas, with forward welding, a larger angle of Vee is necessary for thick plates.



Figs. 76–79.—Backward welding (new "right" welding)

The action of the air is reduced, and the danger of oxidation is less, because the molten end of the welding rod can always be kept in the fluid bath. In addition, slag may be removed more easily than with forward welding, because of the movement, since this removal must be obtained by the blowing action of the

flame. It should further be borne in mind that with backward welding, the flame surrounds the weld which has already been made. It protects the latter, in its glowing condition, from absorbing oxygen and nitrogen out of the air and cooling is retarded. As a rule, therefore, besides being cheaper, backward welding results in a better weld.

At the same time certain provisos must be made. The economic advantages of backward welding first appear on thicker plates, of $\frac{3}{16}$ in. thickness and upwards. With thin plates the direction of welding has a less effect on the workmanship. In backward welding, because of the better way in which the flame is employed, thin plates are burned through. This was also the reason why the transition to this kind of welding was made so late, as the process itself was known. In the very early days of fusion gas welding, when the oxy-hydrogen flame was used, it was generally employed. It was only when people went over to the oxy-acetylene flame, that the welding direction was changed, as the welder could not accommodate himself to the hotter flame and in forward welding he found a means of weakening the action of the flame. Nevertheless, Dr. Wiss had backward welding carried out with acetylene at the beginning of this century.

With vertical seams, backward welding causes difficulties. The torch must always be held so that the flame is directed above, so that the filler material is driven up by the blowing action. In forward welding, the welding is done from bottom to top, and the filler metal is built up on the seam, whereas in backward welding, the process is from top to bottom, so that the filler material must be blown by the flame upwards against the weld, as in overhead welding. This requires special skill which cannot be expected from the average welder.

Hence, we find that for welding in the horizontal position backward welding is more suitable both in respect of quality and cost, for plates from about $\frac{3}{16}$ in. upwards; for thin plates, on the other hand, forward welding is preferable. For the welding of vertical seams, forward welding is more suitable, and for overhead welding it is again to be recommended. A good welder should master both kinds of welding, especially since, in the welding of constructions, it is frequently necessary to change the direction of welding at places which are of difficult access from one side.

When the two-flame torch, which was mentioned on p. 53, is used in conjunction with backward welding, additional advantages may

be realized. As will be shown later, welding consists of four processes, namely, the preheating of the weld zone, the fusion of the weld zone, the preheating of the filler material, and the melting down of this. The welded work is improved if, before the welding process proper, the base material is preheated by means of a special flame. The preheating flame of the two-flame torch fulfils these requirements, and in addition diminishes the work of preheating by the welding flame, so that the heat from this is wholly available for the welding process. Hence a higher welding speed may be obtained and in addition the advantage of a narrower seam may be realized, reduced heating of the adjacent parts is achieved and a reduction in the resulting stresses is effected. According to Keel * multi-flame welding combined with backward welding results in an increase of welding speed to the extent of two to three times.

Another modern process in gas welding which employs a type of two-flame torch, but is based on other characteristics, is that which has been brought out by Linde Air Products Co., the Lindeveld-process.† This differs from the normal gas welding process because of (1) a special setting of the flame; (2) the use of a special welding wire; (3) a new type of welding technique with a new welding torch.

Welding is carried out by means of a flame adjusted with excess acetylene. Because of the metallurgical effect of a flame adjusted in this way, the base material, due to the absorption of carbon, is melted down with the filler material at a relatively low melting point. In addition to this flame setting, welding wire, having suitable metallurgical properties which correspond to the lower melting carburized surface, is used.

As a rule backward welding is used in this process. By moving the torch up and down, it is alternately directed on to the article, and then on to the wire so as to fuse them. In this process, only a very narrow gap is necessary so that savings in filler material, gas and time may be made. By designing the torch as a two-flame torch and by adopting other modifications, the welding speed is increased still further than that of the previously mentioned two-flame torch, and the same advantages are obtained with it as were described with the previous type.

The two flames of the Lindeveld torch do not lie alongside one another, but one over the other. The lower flame is the welding

* *Zeitschrift für Schweisstechnik* (1931), No. 2.
† T. W. Greene, *Journal of the American Welding Society* (1931), No. 10, p. 19.

flame proper, and the upper serves for preheating and melting the wire. By means of a special feeding device the wire is automatically advanced. Consequently the welder only requires one hand for welding, and may carry out all other movements which may be necessary without putting down the torch. In this way the work is considerably simplified.

The process is of considerable importance for pipe welding. The special welding torches which have been described may only be used with advantage when welding in the horizontal position. On the other hand, with vertical welding, an increase in welding output may be achieved with another process which is based on entirely different principles and one which has chiefly been developed in France and Switzerland. It is the so-called "Progress Welding".

Progress welding is generally only used with plates of more than $\frac{1}{4}$ in. thickness. However, with plates of $\frac{1}{8}$ to $\frac{3}{16}$ in. thickness, good results may be obtained. It is unnecessary to bevel the edges which have to be welded. The work is so simple that this kind of welding can be generally recommended. The gas consumption may be reduced to half the quantity normally required; the weld joints are absolutely regular and appear quite satisfactory externally. For plates of $\frac{1}{8}$ in. thickness a torch of 8–8·75 c. ft. per hour should be used. The diameter of the welding wire should be 14 gauge, and the most economical use of filler material should be made. The plates should be tacked at distances of 4 to 6 in., in such a way that after cooling the edges are separated by about $\frac{1}{16}$ in. The torch tip is then brought up to the edges to be welded so that the inner cone of flame strikes vertically on the plates. Without making any movement of the torch a hole ·02 to ·025 in. diameter is melted with the point of the cone of flame. The metal runs to the lower edge of the hole and forms the first joint between the edges. The torch is then guided upwards, making the same circular movement during the whole time, while the same movement is made with the welding wire. Its end must, however, always be kept at the lower edge of the hole. The hourly output of a trained welder amounts to 8 to 9·5 ft., when welding $\frac{1}{8}$ in. thick plates together.

Even if the quality and the economics of welding may be considerably improved by the processes previously described, whether they are based on special manipulation of the torch or an improvement in the torch itself, they are not the only methods which may be used. Complete success in this direction may first be achieved by two processes which affect the arrangement of the whole welding

plant. These are the so-called "Constant Pressure" process and the so-called "Equal Pressure" process. Both presume the existence of central acetylene and oxygen plants, and hence a factory with a large number of welding points. The constant pressure process consists of fixing the oxygen pressure for all welding work and welding torches at 3 atmospheres (45 lb./in.^{2}), by means of a central oxygen pressure regulator, while the setting of the acetylene pressure to 0·3 atmospheres (4·5 lb./in.^{2}) is also obtained centrally by means of an acetylene pressure regulator. If high pressure acetylene is available further equipment is unnecessary, but with low pressure equipment, compression plant with a speed regulator, in addition to the pressure regulator, is necessary.

The equal pressure process goes still further. It requires the same pressure at the welding place for both the oxygen and the acetylene. Pressures of 0·5 or 0·7 atmospheres (7·5–10·5 lb./in.^{2}) are used. The acetylene pressure is fixed either by a pressure regulator or a compression plant and for the oxygen a central oxygen reducing valve of a special type is used. There are also special equal pressure devices both for acetylene and oxygen which are constructed in the form of double membrane valves.

The chief point which is obtained by means of the constant pressure and the equal pressure processes is that the control of the gas pressure and the gas quantity is only left to the welder to a very slight extent, and is transferred to the control of the foreman. In this way, faults in welding, which are due to the wrong adjustment of the flame, are effectively avoided. Increased supervision of the plant is obtained, and control over the gas consumption is easier. If the regulator is connected in just after the oxygen battery, the danger of accidents is further reduced because of the reduction in pressure of the oxygen.

Finally, the processes which are based on the use of a gas mixture, consisting of acetylene and illuminating gas, with which it is desired to reduce the costs of welding by replacing a part of the pure acetylene by the cheaper illuminating gas, should be mentioned. In no case can the replacement of acetylene by illuminating gas be pushed to any high degree, since the quality of the weld is thereby considerably impaired. If illuminating gas is added to acetylene for the manufacture of mass produced articles and for welds which are unimportant, the content should never rise above 30 per cent. Even though a smaller quantity of oxygen is required in unit time, the preheating and welding time is always increased, since the tem-

perature of the mixed gas flame is considerably lower than that of pure acetylene, so that the savings from the use of the cheaper illuminating gas are lost. In addition one cannot point to a reduction in working danger due to the addition of illuminating gas. The value of this mixed gas welding process must consequently be regarded as still open to dispute.

Arc Welding Processes.—The arc, which serves as a source of heat, may be either struck between carbon and carbon, or carbon and metal, or between metal and metal. Hence there are three different processes which were suggested and used more than forty years ago by Zerener, Benardos and Slavianoff.

Zerener used two carbon electrodes which were inclined diagonally to one another, and which he joined to an electric torch with a magnet which he fastened to some suspension gear. The arc, which was struck between the two carbon rods, was blown against the article in order to melt it, by means of a powerful magnetic blow, so as to give a point or soldering flame. The process was more suitable for soldering than for welding, and was more generally used for this purpose, for brass casings, pipes, &c.

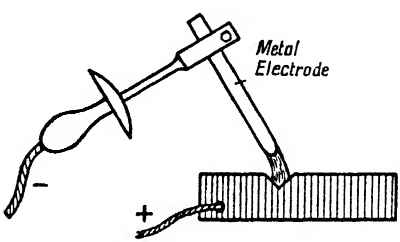


Fig. 80.—Slavianoff's electric welding process

In Benardos's process, the arc is struck between one carbon electrode and the article which forms the other electrode, and which is, therefore, connected to the second pole of the current supply. The article is fused at the point where the arc is formed, and welded either with or without the addition of filler material. In the second case, the filler material is provided by a metal rod which is fused and held in the arc. This process also is used only to a limited extent in the welding of steel and for thin flanged plates, which may be welded without filler material, or it is used for the welding of bronze, cast brass and cast iron.

The process due to Slavianoff has recently acquired a position of importance in welding technology, and to-day is employed almost exclusively. Unless it is otherwise mentioned, the following remarks are entirely devoted to this process.

Slavianoff's process, which is represented diagrammatically in fig. 80, differs from Benardos's process in that the carbon electrode is replaced by a metal electrode, which as far as possible has the

same material properties as the work which forms the other electrode. The arc is struck between the metal rod and the work, so that the latter becomes molten at the weld zone and the metal is transferred to the weld zone as filler material in the arc, at the point of contact between the work and the molten electrode material.

In addition, in arc welding, depending on what kind of current is employed, we distinguish between *Direct Current* and *Alternating Current* welding.

The fusion process takes place in a way which is entirely different from that in fusion gas welding. Whereas in the latter process, fusion of the material takes place before the filler material is added, in arc welding the fusion of the work and the electrode, i.e. the addition of filler material, takes place simultaneously. In this way, the arc always acts upon only a small portion of the weld seam. As soon as it leaves this, the weld solidifies almost immediately, whereas in fusion-gas welding the weld metal stays in the red hot state for a longer time, and cooling takes place slowly.

In arc welding, therefore, as compared with fusion-gas welding, it is more difficult to obtain good fusion of the base metal and the filler metal. Even when satisfactory fusion is obtained, due to the rapid cooling, the weld is harder and stronger, but is, however, very much less ductile. In addition, the fluid material in the arc is surrounded by a blanket of air through which it can easily absorb oxygen and nitrogen, which have a harmful effect, whereas in fusion gas welding this process is prevented by the reducing action of the flame. The absorption of oxygen is especially dangerous, as in this way the weld becomes brittle.

On the other hand, however, arc welding has the extraordinarily important advantage that contractions, as well as stresses and distortions, set up by overheating occur to a very much less extent than with fusion gas welding, especially when the latter is carried out as " forward " welding. The reason for this lies in the fact that the arc only covers a relatively small area, and consequently its heat does not affect the area adjacent to the weld to the same extent as the gas flame. Further, the welding process takes place much more quickly. It will be shown in detail that the greater the welding speed, the smaller the stresses which are set up.

This greater welding speed generally results in greater economies with arc welding.

If it is a question of a choice between fusion-gas welding and arc welding, the following summary may be made.

Fusion-gas welding is to be preferred in all cases where high ductility of the weld seam is required, and also in all cases where large bending stresses occur. Arc welding, on the other hand, is more suitable in cases where stresses and distortions may give rise to danger, which makes the work difficult or impossible. For example, this is so in the welding of large sheets of plate or the welding of plates which are overlapped or set at an angle, or in all cases where there are fillet seams.

For metals with high heat conductivity, such as copper and aluminium, fusion gas welding is practically the only possible process.

Just as attempts have been made, by modifying the direction of welding, to diminish the undesirable effects of fusion gas welding, so processes have been sought, in arc welding, so as to improve the properties of the weld seam, when better ductility is desired. This has led to the use of covered electrodes, the properties of which will be discussed later. The covering is to protect the molten bath and the material which is being transferred in the arc from absorbing nitrogen and oxygen from the air, to cover the fluid weld zone with a layer of slag in order to delay its cooling, and finally to conduct heat from the electrode, so that fusion takes place slowly and the melting of the filler material is made easier. It is, in fact, possible with covered electrodes to obtain a weld, which in respect of ductility is not very different from that obtained with fusion-gas welding.

On the other hand, since the covering of the electrode renders the carrying out of the weld difficult because of the formation of slag, attempts have been made to obtain a protective gas shield directly, by the atomization of a gas which should be as inert as possible. This has led to gas electric processes or arc welding in a gas shield.

Gas Electric Welding Processes.—The atomic hydrogen process and the Arcogen process are to be distinguished as processes which use a gas supply at the same time as an electric arc.

The Atomic Hydrogen Process uses hydrogen as a gas shield. Two processes have been developed. According to the process of Alexander, hydrogen is blown through a nozzle round the arc. At the same time welding is carried out with a metal electrode as in Slavianoff's process. In this instance, however, an atomizing nozzle for the hydrogen is fixed on the electrode. The process is otherwise similar to welding with covered electrodes. The gas shield protects the filler material in the arc from absorbing gases from the air, and

at the same time it covers the weld zone. In this process another phenomenon is apparent.

Due to the high temperature of the electric arc the hydrogen molecules are split into atoms at the electrode with the absorption of a relatively large quantity of heat. In this way, as in welding with covered electrodes, in which heat is necessary to melt the coating, the fusing of the filler material is retarded. When the atoms of hydrogen meet the work, the atomic form of hydrogen, 2H, reverts once more to the molecular form, H_2, and the heat, which has been absorbed to split the molecule, is given up. With this process, therefore, the result is that due to the bombardment of the hydrogen atoms on the work the heat which is given out heats up the latter, which is rendered more quickly molten than in welding without a gas. In addition, the cooling of the weld zone is thereby delayed. From the technical point of view, the process is similar to the fusion-gas welding process. The weld possesses the well known appearance obtained with fusion gas welding. The intense heat makes it further possible to butt weld together plates up to $\frac{9}{16}$ in. thick without bevelling the edges.

It has been shown, however, that the arc behaves differently in various gases. Whereas a voltage of 20 volts is sufficient to maintain an arc, which has been struck in air, in order to maintain it stable in hydrogen, a voltage of about 80 volts is necessary. For this process, therefore, special welding transformers are necessary.

By means of the process which has also been termed "Welding with Atomic or Dissociated Hydrogen" it was intended that the advantages of electric and fusion gas welding should be combined to a certain extent, and the disadvantages correspondingly reduced. The process, however, is very difficult to carry out. In addition to guiding the electrode, the welder must attend to the feed of the nozzle and this adversely affects the way in which the electrode may be manipulated. Consequently the process has been abandoned for hand welding, and has only been developed for machine welding.

On the other hand, a further process for hand welding with atomic hydrogen has been developed according to the process due to Langmuir. The process is carried on in such a way that an alternating current arc is struck between two tungsten electrodes which are set at an angle to one another in a holder similar to that used for the carbon electrodes in Zerener's process (see fig. 81). Through this arc, hydrogen is fed on to the welding zone. The splitting of the hydrogen molecules in the arc, and their recombination

in the weld zone due to the heat of formation being given up, takes place just as in the Alexander process, that is, the heat of formation is utilized slowly for melting the metal. The only purpose of the tungsten electrodes is to maintain the arc, and they take no part in the welding process itself.

Manipulation is identical with that used in oxy-acetylene welding. The tungsten electrodes constitute a torch without there being any combustion of gas, and the filler rod is held in the gas stream. In this process protection is also provided for the molten zone against the absorption of gases from the atmosphere and cooling is also delayed.

By the use of various voltages, arcs of different strengths may be produced so that it is possible to adjust the temperature required to the amount of atomic hydrogen which is generated, which must

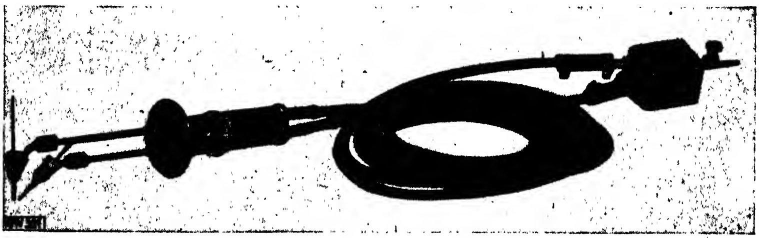


Fig. 81.—Welding equipment for Langmuir's atomic hydrogen process

be varied in accordance with the thickness of the articles which are to be welded together.

The process is especially suitable for the joining of thin plates, for non-ferrous metals, and certain of their alloys, and also for the welding of alloy steels and manganese steel.

*The " Arcogen " Process,** which has recently been discovered and developed by the firm I. G. Farbenindustrie A.G., Griesheim, in collaboration with the Allgemeine Elektricitäts Gesellschaft, is a direct combination of fusion-gas welding and arc welding. In his right hand, the welder guides an ordinary torch, which is the same size as that used in fusion-gas welding, and in his left hand holds the welding rod. The welding rod is, at the same time, an electrode which is connected to one pole of an alternating current supply, as in welding in air, and the article is the other pole. The welding zone is fused by means of the gas flame, and at the same time the arc is struck so that the electrode melts, and the filler

* Münter, "The combined autogenous electric weld process 'Arcogen'" *Autogene Metallbearbeitung*, Vol. 23 (1930), pp. 328, 349, 365.

material in the arc is transferred to the article under the protection of the gas flame.

A difficulty is now apparent, and that is to maintain the arc. With an acetylene flame, we are not dealing with stationary, but with rapidly moving gases, in which the arc will be extinguished, as it is not in a position to ionize sufficiently the streams of gas which are rapidly being renewed.

By means of a chemical paste which is put on the electrodes, it was found possible to raise the electric conductivity of the welding flame about a thousand times. The conductivity of the flame is improved by the paste to such an extent that, in order to strike the arc, it is no longer necessary to touch the article with the electrode as is necessary to strike the arc when welding is carried out in air. As a rule the arc is struck automatically, as soon as the flame touches the end of the electrode. The welding voltage amounts to about 33 volts, whereas the current strength is only about 58 amperes, so that the current consumption is only about half that which is used in arc welding in air. However, as the consumption of gas must be added to the consumption of current, and as moreover one must have a plant for the arc welding, as well as the equipment for fusion gas welding, the welding costs of the Arcogen process, per unit of time, are about 50 per cent dearer than fusion gas welding and correspondingly higher than for arc welding. On account of the welding speed, which is twice as great, these increased costs should not only be covered, but it should be possible to achieve savings of about 33 per cent.

It should be noted that in the "Arcogen" process alternating current has shown itself superior to direct current. Flames have the property that when direct current is used a positive flow in the reverse direction is set up, which disturbs the equilibrium and stability of the arc. This is due to the unipolar character of the flame, which assists flow of positive electricity but retards that of negative. With alternating current, however, there is no polarity, and consequently no opposing action between two directions of flow.

These remarks will serve to show that the "Arcogen" process ought to combine the advantages of fusion-gas welding and arc welding, in so far as good fusion of the article, before the addition of the filler material, should ensure the protection of the weld zone against the absorption of gases from the air, and should ensure its slow cooling. It is questionable to what extent it is possible to avoid

stresses. In this respect it has been shown that the "Arcogen" process occupies a position between the other two processes. This is understandable since we have the effect of a double flame, but at the same time double the speed is obtained, and in addition the weld Vee may be kept very narrow. Even for thick plates it is unnecessary to machine out the groove to the Vee or X form.

The "Arcogen" process is suitable for the welding of steel for plate thicknesses of $\frac{3}{16}$ in. upwards, and in addition for copper and aluminium. It is unsuitable for materials which are sensitive to overheating such as thin plates; it is also unsuitable for vertical and overhead welding and for fillet seams.

As far as manipulation is concerned, welding with polyphase current is similar to the "Arcogen" process. Once again it is a purely electrical process, but it is discussed here in connexion with what has previously been stated. In the same way as the welder guides the torch in the "Arcogen" process, so with polyphase current he guides a covered electrode in his right hand with which he carries out the welding movements proper, and in his left hand he once more manipulates a bare electrode. The fear may be expressed that guiding and observing two electrodes can hardly be done with success, since working with one electrode is difficult enough. As a matter of fact, the welder only needs to observe carefully the main electrode. The bare electrode behaves in this case exactly as in "Arcogen" welding, in which it strikes without more ado, as soon as it reaches the gas shield which emanates from the covered electrode. In addition, the transfer of drops from it is protected by the gas shield so the question of maintaining an exact distance from the article does not arise. In consequence an advance similar to that which can be achieved by the "Arcogen" process may be achieved with welding with polyphase current. The tests with a new polyphase current transformer have not gone far enough to enable a definite attitude to be adopted towards it.

(*b*) PREPARATION FOR WELDING

The careful setting up of the work, taking due account of the stresses which are to be expected, and a well chosen arrangement of the welds in the construction, are of considerable importance for the success of welding. The types of construction which have proved suitable when riveting has been employed cannot be adopted as was frequently and mistakenly done originally, but they must con-

form to the requirements of welding. There are a large number of occasions when the preparation for fusion-gas welding and arc welding is similar; in other cases different methods must be adopted. Therefore, when discussing both kinds of welding at the same time, it is as well to bear in mind the requirements of both. In general the following remarks relate to the welding of steel, but at the same time they also hold for the welding of non-ferrous metals, in so far as special precautions, which will be discussed separately in the following sections, have not to be taken. The welding of cast iron occupies a special position as far as preparation and workmanship are concerned.

The first preparation for welding which should be obvious, but to which insufficient attention is frequently given, thereby giving rise to imperfections, is to clean the metallic surfaces which have to be welded. Rust, oil, paint, and dirt give rise to the formation of slag and bad joints. Consequently, the welding rod should also be clean and free from rust.

After this, it is generally necessary to prepare the articles further by flanging, bevelling or Veeing.

We have to distinguish between

Butt welding for the welding of plates in the horizontal or slightly inclined position;

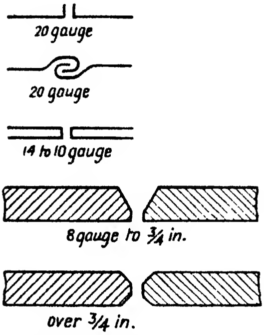
Fillet welding for the welding of plates which are inclined at a large angle to one another or lapped or joined together by means of cover straps;

Building-up welding, which serves the purpose of restoring to their original condition parts which have been worn away during service, or of covering new or worn parts with a hard wearing surface (Hard Welding).

Apart from the cleaning of the welding surfaces, it is unnecessary in fillet and building-up welding, to make any further preparation before putting down the weld run. In butt welding, however, the articles must usually be so prepared that a *Weld Groove* is formed, which is to be filled with filler material. This may only be omitted with plates from $\frac{1}{16}$ to $\frac{1}{8}$ in. thick, which are butted against one another, as is shown in fig. 84, and in such cases it is advisable to choose the distance of the plates from one another as $\frac{1}{64}$ in. for $\frac{1}{16}$ in. thick plates, and $\frac{1}{32}$ in. for $\frac{1}{8}$ in. thick plates. With plates of these thicknesses, it is an advantage to lay a backing plate underneath the weld to conduct the heat away, otherwise it is easy to burn holes in it.

Thinner plates are flanged or folded according to figs. 82 and 83. The flange or the fold is melted down between the plates by means of the flame or the carbon arc and provides the filler material for the groove.

With plates of $\frac{1}{8}$ in. thickness and upwards it is necessary to prepare a wider welding groove by bevelling the plates, so as to make it possible to weld through right to the under-edge of the plate. When fractures are being welded, a weld groove of this kind must be made by cutting out the faulty piece down to the base. This groove may be made either Vee-shaped by bevelling the plate up one side, as is shown in fig. 85, or by bevelling both sides and making it X-shaped, as is shown in fig. 86. Previously the Vee-shape was used for plates up to $\frac{3}{8}$ in. thick; for thicker plates the X-shape was used, bearing in mind that the weld zone has a cast structure, and therefore it is desirable to limit its volume as far as possible. The X-seam has, however, an important disadvantage unless welding can be done simultaneously from both sides. For reasons which will be advanced later, this is preferably done with copper, but is seldom done with steel. While the first side is being welded, the filler material usually drops through the root of the groove and solidifies into hard drops. These drops which are covered with an oxide skin block up the section of the groove on the other side, and are difficult to melt down during the welding of the second side. With this arrangement, therefore, attention must be paid to avoiding the formation of oxide inclusions and hollow spots in the root as occur with the welding which is illustrated in the etched photograph in fig. 87.



Figs. 82–86.—The preparation of various thicknesses of plate for welding.


Fig. 87.—Microscopic photograph of an X weld

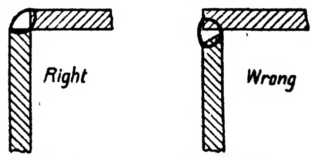
Nowadays narrower angles are preferred where possible, and Vee-shaped grooves are employed for plate thicknesses up to $\frac{3}{4}$ in. Beyond this one has usually to go to the X-shape.

When broken parts are being repaired, a suitable groove of V- or X-shape is made by cutting out the fractured portion.

With arc welding or gas backward welding, a bevel of the plate of 30° is sufficient for plates up to $\frac{3}{8}$ in. thick, so that the weld angle amounts to 60°. For greater thicknesses, a large angle is chosen, according to the plate size, so that for a $\frac{3}{4}$ in. thick plate, an angle of 75° is obtained. With X-shaped welds starting at $\frac{3}{4}$ in. plate thickness an angle of 60° is used. For gas forward welding, larger angles are invariably necessary in order that the effect of the flame shall penetrate into the root of the groove.

It is usually recommended that the bevel on the plate should not extend over the whole thickness of the plate, but that it should be left unbevelled at the root of the groove for $\frac{1}{4}$ the plate thickness, as is shown in figs. 85 and 86. This is to prevent the accumulation of heat at the sharp edges of the plate from causing the plate material to overheat and burn. Experience has taught that with this arrangement, the groove at this point is difficult to fuse, especially with thick plates, and consequently insufficient penetration is obtained. The welder finds it much easier to avoid the former mistake than the latter. Consequently, it is often better to dispense with this arrangement of the groove and to bevel the plates for the full thickness. In any case, with gas backward welding, it is advisable to extend the bevel for $\frac{3}{4}$ of the plate thickness, since the depth to which the flame acts is greater.

In all cases, the distance apart of the plates should be $\frac{1}{16}$ to $\frac{1}{8}$ in. for both the V- and X-shape of groove.



Figs. 88 and 89.—Right and wrong preparation for corner seams on containers.

When the welds are being arranged in the construction, it will not always be possible to make an angle of V having the dimensions given above. If a choice between various constructions is possible, it should always be borne in mind that too narrow an angle endangers the quality of the design, and it is better so to arrange the weld seam that the groove permits of good fusion. As an example, if a corner weld is being made, the type shown in fig. 88 will be chosen and not that shown in fig. 89, which has too narrow an opening.

At the beginning of the design of the construction, the designer must pay attention to making the weld accessible. It must be so situated that the flame or the arc can penetrate into the groove, and further, that the welder can work in the most comfortable position

possible, since only then is it possible to carry out careful work. Welds, which have to be made overhead, are to be avoided as far as possible, since in this position a quality comparable with that obtainable with horizontal seams can never be realized. Vertically welded seams are also unsatisfactory from the point of view of quality, but they can seldom be avoided in welding on site, and also when welding unwieldy members in the workshop. A clever designer, however, can do a great deal to improve the quality of the weld.

Apart from the points which have been mentioned, there are two more which are very important in the arrangement of welds in the construction, viz. the recognition of stresses set up during service, and the avoidance of stresses due to the heating of the article during welding, and the distortions which are experienced during cooling.

As far as possible, the weld should be so positioned that only tensile and compressive stresses are set up. A soundly made weld will always stand up to stresses of this kind. The weld seam is more sensitive to shear, but in many instances this arrangement cannot be avoided. On the other hand, care should be taken never to subject the weld to bending stresses. It must always be borne in mind that the weld seam has a cast structure which does not possess the same ductility as the base metal.

For this reason, it is definitely bad to select corner joints, as shown in fig. 88 or 89, for vessels which are subjected to pressure, because they will be stressed in bending when the walls of the container swell out during service and then return to their original position. The only correct type is according to fig. 90, in which the weld seam is stressed in tension. Equally bad is the arrangement shown in fig. 93 for junction welds between flanges and pipes. Two mistakes have been made in this case. The weld groove is too narrow, and is in addition stressed in bending. The first mistake may be got over by the arrangement shown in fig. 92, but the best arrangement is that shown in figs. 91 and 94, where the seams are stressed in tension.

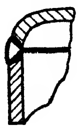


Fig. 90.—Arrangement of a corner seam on a pressure vessel.

It is equally bad to use a V- or X-shaped bevel for an angle joint, as shown in figs. 95 and 96. It is impossible with this arrangement to get as safe a joint as that shown in fig. 97, which is the only correct one.

It is of the greatest importance to take into account the *Heating Effect of the Welding Flame and the Arc* on the material surrounding the weld, and this should be done in the preparation of the plates for welding and in positioning them in the construction. This is very important, as was mentioned when discussing various processes, and especially so with fusion gas forward welding, since the effect of the flame is spread over a larger portion of the plate near the weld zone. At the same time, even with fusion gas backward welding and arc welding, precautions are necessary.

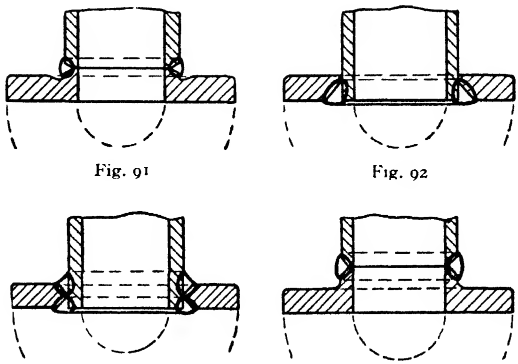


Fig. 91 Fig. 92 Fig. 93 Fig. 94

Figs. 91–94.—Welded joints for pipe flanges

Due to the heating, the plates expand. If they are laid together with an equal gap along their whole length they will tend to overlap one another in the way which is indicated in fig. 98. It is then impossible to continue the welding. This overlapping will be increased, depending on the magnitude of the heating effect on the surrounding plate, and decreased if it is possible for the plates to expand in the

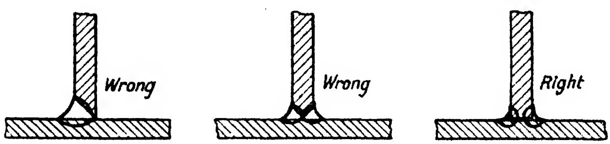


Fig. 95 Fig. 96 Fig. 97

Figs. 95–97.—Right and wrong types of welded oints on angle joints

opposite direction. This is always so with large sheets of plate. Hence care must be taken, during preparation for welding, that the plates cannot overlap one another. In arc welding, it is sufficient to tack the plates before welding in the way shown in fig. 99. The tacks, which should be pitched at 6 in., should be small, so that they are completely melted down when the welding is carried out, as otherwise they may give rise to faulty spots. The tacks are first made at two ends of the seam and then two tacks are put in the

middle and so on, until the required pitch of the tacks is obtained. If one tries to make them in a row, starting at one end, it will be found that the tacks which have been made, will crack due to the elongation caused by the heating of the plate, which will set up a bending moment.

Since the plates are prevented from expanding during welding, stresses are set up along the seam, but these can be kept so small, in arc welding, that they do not give rise to bulges and contractions. This is done by adopting a suitable order of welding (step-by-step welding), which will be discussed in greater detail in the following pages. Conditions are more difficult with gas welding. The heating is considerably greater and it requires different precautionary measures, especially with thin plates. When one tack has been made, the stresses, which have been set up during welding will undoubtedly cause the plate to buckle. The plates are therefore laid together in such a way that the gap increases in the direction of welding, as may be seen from figs. 100 and 101. A suitable dimension for the distance between the plates is $\frac{1}{16}$ in. per foot weld run, when forward gas welding is employed and thin plates are used. When gas backward welding is employed and thicker plates are used, the increase in width of gap may be kept smaller. In spite of this, in order that the plates should not overlap one another, their position is maintained by means of a wedge, as shown in fig. 101, or by means of two crossed steel bars. At the same time, this method makes it possible to maintain the vertical position of the plates on both sides. Depending on the speed at which welding proceeds, and the extent to which the plates are drawn together during heating, the wedge or bar is gradually pushed forward. In this way, tensile forces are set up due to the tendency of the plates to contract, and compression forces due to the resistance to this contraction, provided by the wedge. The tensile and compressive stresses must balance, if a seam which is free from stress is to be obtained. The welder himself will best learn, from experience, how large a wedge angle to choose and at what distance he should keep the wedge from

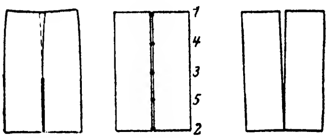


Fig. 98 Fig. 99 Fig. 100

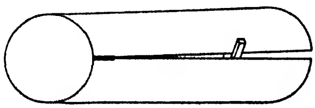
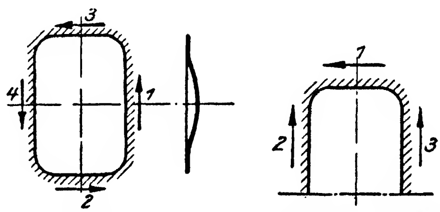


Fig. 101

Figs. 98–101. — Precautions against temperature elongations when welding plates.

the welding flame, in order to complete a weld without buckling.

On cooling, the weld definitely tries to contract because the solidifying process is bound up with a reduction in volume. Moreover, during welding, the edges of the seam have come nearer together. Contractions therefore occur, which in turn set up stresses, which cause distortions as displacements in the plane of the plate. According to Lottmann, these contractions, for V- and X-seams with arc welding, amount to about 0·024 in. per foot run in a direction at right angles to the seam, independent of the plate thickness. Stresses and distortions will follow contractions to an extent which is greater the less the construction allows the parts, which are being welded together, to expand in a direction parallel to the weld seam. As far as possible, therefore, rigid parts should be avoided during the design of the construction and also during erection, by adopting an order in which the weld seams are made, so as to try to guard against rigid fixing.



Figs. 102 and 103.—Welding of patches on to plates

For example, in the welding on of patches, which are frequently necessary in the repair of containers and boilers, due to rusting or cracks, it is most satisfactory to put these on so that they stop short at the edges of the article on one or two sides, and in this way the patches may freely expand and contract in this direction during the welding and cooling of the weld. When the weld is being made, that side of the patch which is parallel to the free edge is first welded, and only after cooling will the welding of the other be carried out, in the direction indicated by the arrow in fig. 103. With fractures at rivet holes, the rivets should always be taken out for such a distance that the plate can freely expand during welding. There are other precautions to be taken to nullify the effect of contraction during the cooling of the weld seam. For example, if the patches, which have been mentioned above, have to be put on so that they have to be welded from all sides, it is helpful to choose them somewhat larger than the space to be filled and to dish them before welding. Due to contraction, they distort into the plane of the plate, if the dimensions have been chosen correctly, and experience soon enables this to be done. The order in which the seams are welded is selected

in accordance with that given in fig. 102. The corners of the patches should not be sharp but rounded off as far as possible.

Because of the arrangement of the weld seams in the construction, it will not always be possible to limit to a minimum the difficulties which occur due to distortions and contractions, to such an extent as to render them unimportant. In such cases, a weld process should be chosen in which the heating is as small as possible. It is scarcely possible, therefore, with lapped plates and cover straps to make a good weld with a gas flame. In fillet welding, the arc welding process will invariably be preferred. The most suitable type, for gas welding, is butt welding with the plates in the horizontal position.

For example, under the influence of the flame the thin plates which have to be lap welded will part from one another, as may be seen from fig. 104, or if tacked before welding will distort out of the plane of the plate. Arc welding, therefore, is better for this case, but at the same time there are special precautions, which will be discussed later, to be observed during welding. Thicker plates may perhaps be welded in this way with gas, provided some care is taken, but only one edge should be welded and not two, as in

Fig. 104.—Effect of heating during welding on overlapped plates

Figs. 105 and 106.—Welding of straps and lapped plates

fig. 105, although this arrangement, in itself, would be more satisfactory. The contraction, which would be set up in fusion-gas welding, when the second seam was welded, would undoubtedly lead to too high stresses, and as a rule to fracture of the first seam, since the plate is now to be regarded as rigidly held, because of the first weld. Arc welding is the only possible process, for the same reason as when strapped joints are being made, as shown in fig. 106. In this arrangement also, if double lapping is employed, it is better to leave the butt joint between the plates unwelded, since the figure shows that, during the welding of the fillet seams on the straps, an opportunity is given to the plate to move. If this is not observed, the butt weld may easily fracture during the welding on of the straps, without its being noticed. Strap joints of this type, which are frequently recommended as strengthening straps for the reinforcing of a butt weld can, on the contrary, frequently be termed

non-strengthening straps. The simple butt weld is, as a rule, safer than such strapped constructions.

Setting up the Article.—In conclusion, it is relevant to the preparation for welding, that one should keep an eye on the most suitable and accessible way of setting up the article. If it is at all possible in the welding workshop, large objects should be set up so that they are accessible from all sides, without the welder having to adopt an uncomfortable position, which he cannot maintain for a long time. Small articles are best set up on the welding bench about the height of the welder, so that the welder can work sitting on a stool. Whether the weld is arranged to be at right angles to the position of the welder or in the same direction, depends on the skill and habit of the welder.

During erection, it will not always be possible to arrange the seams, which have to be welded, to be comfortable for the welder; at the same time a great deal can be done during the design of the construction, which will conduce to the elimination of difficult positions.

(*c*) MAKING THE WELD

Even if a considerable number of precautions have to be taken when preparations are being made for fusion-gas welding, which differ from those for arc welding, at the same time, the way in which the weld is carried out in both processes differs fundamentally. They will be treated separately in the following pages. It will be shown that the differences, not only in the guiding of the torch and the electrode, but also in the treatment of the base metal, are so great that at the outset, one should avoid letting a gas welder do arc welding and vice versa, or changing them over from time to time. This is frequently regarded as permissible and even as advisable.

Gas Welding

In gas welding, which will be discussed next, it is of fundamental importance that the welding flame should be set correctly.

The Welding Flame.—The flame is formed by the combustion of a combustible gas with oxygen. The combustion should be complete, since a non-combusted portion of the gas usually has a harmful effect on the weld. Excess oxygen which leads to oxidation of the weld metal, and the formation of slag, is equally dangerous. Conse-

quently, the combustible gas and oxygen must be present in a definite proportion to one another, and therefore must have been already mixed in the torch in quantities corresponding to this proportion. The quantity of oxygen, which is necessary for complete combustion, varies with different combustible gases such as acetylene, hydrogen, benzol vapour, &c. With acetylene it amounts to five volumes of oxygen to two volumes of acetylene. Since the flame, however, takes oxygen from the air for combustion, it has proved practicable to provide a mixture of acetylene and oxygen in the ratio of 1–1·1 up to 1·2. If the mixing ratio varies during welding, due to variations in pressure in the generator, the lines, or the oxygen cylinder, or due to the heating up of the torch (compare p. 51), the flame must be adjusted forthwith.

Fig. 107.—Correct setting

Fig. 108.—Flame with excess acetylene

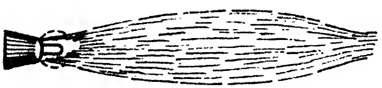


Fig. 109.—Flame with excess oxygen

Figs. 107–109.—Appearance of the welding flame

The setting of the flame is comparatively simple when acetylene is used as a combustible gas, since excess acetylene as well as excess oxygen show this clearly by their appearance.

With a correctly set flame, as is shown in fig. 107, a strongly illuminated, bright yellow, long flame is clearly seen at the tip of the torch and in front of this a rounded cone. Broken edges or a sharp appearance of the cone indicate a damaged or dirty torch tip. The torch tip must then be changed or cleaned.

If excess acetylene, which would lead to a carburization of the iron, exists in the flame, the cone loses its sharp definition, as is shown in fig. 108, and takes on a pale illuminating appearance; the acetylene must then be throttled down. On the other hand, with a deficiency of acetylene and excess oxygen the flame gives a short violet cone, as in fig. 109.

The combustion of acetylene takes place in the flame in two stages. In the illuminated cone of flame, there is a mixture of almost entirely free oxygen and uncombusted acetylene. Immediately afterwards, the acetylene (C_2H_2) suddenly decomposes into its two constituents, carbon (C) and hydrogen (H), so that the carbon combines with the oxygen (O), which is present in the torch to form

carbon monoxide (CO). This may be represented in a chemical formula as follows:

$$C_2H_2 + 2O = 2CO + H_2.$$

Due to the speed with which it takes place, this process, which may be distinguished in the sharp edge of the illuminating cone, does not represent complete combustion of the combustible gas, since carbon monoxide and hydrogen are both combustible constituents of the flame. These, therefore, draw oxygen from the air for their further combustion in the second zone, and this combines in the third flame zone with the carbon monoxide to form incombustible carbon dioxide and with the hydrogen to form water. Expressed in a chemical formula the second combustion process is as follows:

$$2CO + H_2 + 3O = 2CO_2 + H_2O.$$

It therefore obviously follows that the middle zone, which is suitable for welding, is a zone having a reducing effect and in this zone the maximum temperature of 5500° F. (3000° C.) is developed If the cone of the flame is brought on to the article, the free oxygen which is contained in it would lead to the burning of the base metal. This is easily observed, because a violent shower of sparks occurs in which the sparks, which are thrown out, break up at the end of their flight into star-shaped pieces, whereas with a correctly set flame, the sparks retain the closed spherical shape. On the other hand, if the flame is kept too far away, harmful effects on the welding seam are set up, because the water vapour, which is present, splits up into its components, hydrogen and oxygen, on account of the excessive heat. In addition, it is at this point that the harmful effect of oxygen and nitrogen from the air occurs.

It is important that the flame should burn quietly, should not be extinguished, and should not strike back in the torch. Hence, the exit velocity of the gases must be such as to exceed the ignition velocity. If the former is too high, the flame is projected too far. If it is too small the flame strikes back in the torch. Hence, the pressure drop, which occurs with oxygen cylinders which have been emptied too far is very disturbing. In these circumstances, the exit velocity of the gases may be suddenly reduced, due to the sudden expansion causing freezing, when the oxygen flows out of the cylinder valve, or when the oxygen supply is totally or partially cut off, as occurs if the gas hoses, which are lying on the ground are trodden on. A further cause of striking back is that which has already

been mentioned, namely, a variation in the pressure conditions due to a too intense heating of the mixing chamber, or to choking of the torch nozzles or to leaks in these.

The adjustment of a *Hydrogen Flame* is much more difficult, because the cone of flame, which is coloured blue to bright violet, does not stand out very clearly from the flame, and is therefore difficult to recognize. Considerable experience is necessary to weld safely with this flame, since a point which lies only a few sixteenths of an inch in front of the flame tip can be used effectively for welding. The only indication that the cone of flame has been brought too near the article is a dark point, which appears in the flame, and which is caused by the cooling of the metal surface by the uncombusted gas mixture present in the cone.

The *Benzol Flame* is similar to the acetylene flame, while the illuminating gas flame is more like the hydrogen flame.

Manipulation of the Torch.—When types of welding were being discussed, it was previously mentioned that, during forward welding, the torch was oscillated and guided along the welding groove, so that it impinged on the edges equally, while the welding rod was moved in a straight line in front of the flame. On the other hand, for the type of backward welding, which is generally used, the torch is held in a straight line and the welding rod is moved behind the flame with an oscillating motion in the molten bath. At the same time, it is not intended to convey that the movement must be made exactly as that shown in the illustration, in figs. 68 to 79. Good welds cannot be made mechanically and systematically. They require consideration, skill, and experience, which can only be obtained through practice. The most important thing is that the welder should learn to observe and follow exactly the fusion process in the weld seam, and should control it so that the article at the edges of the weld is nicely fluid, the filler material is fused in with it, and a real welding of the two takes place, not an adhesion. In addition, the base metal should not be overheated or burned, and finally no pockets should be formed due to gas. In order to learn these points, good instruction and practice are necessary. Therefore it appears misguided to give definite instructions for guiding the torch.

It will be seldom possible to travel uniformly in the direction of the weld and add filler material evenly. The torch will frequently have to be moved backwards, especially at the moment when filler material has been added, in order to keep the molten bath uniformly fluid and to drive out slag.

It is a mistake to keep the torch at one place for a long time, since in this way the material is overheated, and it is also wrong to let the flame move out sideways from the weld seam, since the hot weld zone is then free and exposed to the action of oxygen from the air. On the other hand, moving the flame away for a short time during welding is not so dangerous, although a warning is frequently uttered against it. An unskilled welder should avoid it, but an experienced welder frequently uses it in order to bring slag, which is enclosed in the molten bath, to the surface, or in order to close up pores.

If two plates of different thicknesses are to be butt welded, it will be obvious that the flame should be concentrated on the thicker plate, in order to keep the edges of the thicker as molten as those of the thinner.

With forward welding, it is preferable, with thick plates, to fill up the bottom of the groove first, for a length of about $\frac{3}{8}$ to $\frac{9}{16}$ in., and then to increase the size of the weld by going backwards and forwards until the weld groove is completely filled up. In this way a sloping surface is formed in the direction of welding from which one travels in the direction of the seam, in order to weld it completely. It has also proved advantageous to hammer the weld with a round-headed hammer as soon as it has been filled to a depth of $\frac{1}{8}$ in. Special care should be taken when doing this so that the hammering takes place at red heat. By means of this treatment, a considerable improvement in the quality of the weld is obtained.

A further improvement in the weld may be realized by suitable subsequent treatment. By subsequent annealing the structure is refined. Hammering at red heat after welding, on plates which are not too thick, will give the same result as hammering during the weld process. With thicker plates it is recommended that an intermediate treatment by hammering during welding, should be made.

In backward welding, however, the filler material is put down in the welding groove until the latter is completely filled, that is to say, in one run before proceeding farther with the torch. Hammering also helps to improve the quality of the weld, if it is carried out at red heat, but as a rule, this cannot be done, as the welding process should not be interrupted. Therefore a penetrating effect is not obtained, and the improvement in quality is largely restricted to the surface. As a rule, therefore, it is avoided, and wherever smooth seams without a weld reinforcement are required, forward welding is used.

British manufacturers against the Indian millowners to retard the growth of the cotton industry in which millions of rupees were invested. After a great deal of controversy, the Acts of 1881, 1891 and 1911 were passed. The Factory Acts of 1881 and 1891 did, of necessity, bring about some depression to the industry.

Other Influences.

The history of the cotton industry from 1892 to 1900 is an eventful one.

The high price of raw cotton from 1892 onward seriously reduced the profits of the manufacturers and there were no two consecutive years in which they were working under normal conditions.

The Indian Industrial Commission (page 73) has truly observed:—

> "The closing of the Indian mints in 1893 to the free coinage of silver, together with the industrial development in recent years of Japan, which now not only supplies its own needs but is a keen competitor with India in the China yarn market have to some extent retarded the rapidity with which the Bombay yarn industry was previously expanding."

In 1896, the shadow of the famine fell over the industry and the outbreak of plague in the Bombay City caused an exodus of the inhabitants which for the time almost stopped the working of the mills. Since then the industry suffered an acute crisis, the culmination of which may be seen in the reduction of the output of yarn from 514 million lbs. in 1899-00 to 353 million lbs. in 1900-01.

Mr. O'Conor's Review of the Trade of India in 1899-00 describes in detail the causes:—

> "The truth is many......mills were established in the interests of those who financed them, their remuneration being a commission on each pound of yarn spun, without reference to its sale at a profit. The inducement to excessive production is manifest. A second reason...... lay in the exclusive attention given to China...... market. The Agents had no interest to seek out a

tion), due to the vast abundance and relatively cheap supplies. This indicated the improved spinning efficiency and a demand for finer staples.

The year 1911-12 which witnessed the fall in the price of raw cotton was of bad omen for our spinners. Later on, the fall in the price of the raw material synchronised with improved conditions in China, and evoked an exceptional demand but almost immediately after heavy contracts had been made for shipment, the revolution in China created a situation which was only saved by the development of an internal demand. The output was estimated to be about 75% of the maximum of which the industry was capable.

A glance at any statistics showing progress of production and export of yarn will clearly show that there is a steady increase. Till 1905 there was a steady decrease in imports of yarn for hand-looms. We produced higher counts of yarn here. The increase in imported yarn in 1905 was due to the increasing demand of finer counts and decrease of import in long-stapled cotton. The table shows the quality of yarn produced.

They will also show that during the 14 years from 1900, we have made a fairly rapid advance in production of grey goods. (In 1897-8, about 91% of goods were unbleached and grey, and in 1913-14, only 40% were such—this points to an improving situation) in spite of several difficulties, referred to above, like plague, famine, the 1905 overproduction crisis, the high price of raw cotton after 1907, the effects of the excise, and the silver tax, (which we will consider shortly). We have already noted the prominent causes of depression, *viz.,* overproduction due to the mill agents' remuneration being a commission on each pound of yarn produced irrespective as to whether the outturn was sold at a profit or otherwise, and the exclusive attention to the foreign market. Referring to the system in most of the Bombay mills of remunerating agents not on profit but by commission upon outturn, the Cyclopoedia of India writes:—

> "The internal management demands a radical reform and needs to be purged of the many corrupt practices which are a reproach to their morality. Simultaneously, the burdens and system of commission on the production, at the rate of one quarter anna per lb. urgently demands

> replacement by a fair and reasonable rate of remuneration.[9]

The export of piece-goods was comparatively insignificant and shows no rise. The imports are steadily rising which points to the fact that Indian mills could not supplant Lancashire ones, that the coarser quality of goods formed only a part of the demand of the population.

It was thus clear that in order to oust the foreign manufactures, the mills had to go on producing finer goods, if necessary, by importing long-stapled cotton and by improving their old-fashioned methods of dying, bleaching, mercerising, finishing and making them up-to-date.

The foreign demand, *e.g.*, of China, of our goods is always precarious and unstable. Therefore in our interest, we ought to develop the home-market. The action of the excise duty which leaves the yarn untaxed but affects the weaving industry, may have been partly responsible for this neglect of developing the home market.

The Hon'ble Mr. Manmohandas Ramji[10] dispelled the belief that the development of home-market was impossible in view of foreign imports, thus:—

> ......"The development of the home-market should ever be an ideal placed before us. Because the country does not manufacture variety of goods at present, it does not follow that it will not be able in time to come to manufacture them. The working of the mill industry in this country shows how the production of certain goods considered impossible before, is now going on apace. Similarly, the mills, if afforded proper scope for development, will be producing finer varieties of piece-goods."

The Silver Tax in 1910-11.

The Chairman of the Bombay Millowners' Association said that the silver tax had transferred the yarn trade from Bombay to Japan. If it be true, it corroborates the anticipation of the Hon'ble

9 The Cyclopædia of India, II, p. 27; pp. 264-272 give a good account of the industry.

10 See his speech in the Annual Report of the Bombay Millowners' Association.

chosen than for thicker materials. As a rule, it is customary to weld with 8-gauge electrodes, and thinner electrodes only are used with light plates. For thicker plates, and in building-up welding, electrodes from 6- to 4-gauge are used to increase the welding speed, but, if too thick electrodes are chosen, this is always attained at the expense of the quality of the weld, since the depth of penetration is then reduced, as will be discussed later. A thickness greater than 4-gauge, therefore, should not be exceeded, otherwise current strengths greater than 200 amperes have then to be used, for which normal welding dynamos and transformers are not constructed. These are then overloaded and are ultimately damaged.

For various plate thicknesses, therefore, electrode thicknesses and ampere values should be chosen as follows:

Plate Thickness	*Electrode Diameter*	*Current Strength*
$\frac{1}{16}$ to $\frac{1}{8}$ in.	14 G.	45 to 60 amp.
$\frac{1}{8}$ to $\frac{3}{16}$ „	12 G.	60 to 80 „
$\frac{3}{16}$ to $\frac{1}{4}$ „	10 G.	100 to 120 „
$\frac{3}{16}$ to $\frac{3}{8}$ „	8 G.	160 to 180 „
over $\frac{3}{8}$ „	6 G.	180 to 220 „
	4 G.	225 „

Manipulation of the Electrode.—During the welding process, the manipulation of the electrode differs considerably from that of the torch, since in arc welding, the fusion of the base material and the addition of filler material takes place simultaneously, whereas in gas welding, the base material is melted by means of the flame before the filler metal is added.

Further, it should be noted that the arc should fuse deep down into the article: as is said, it should bite into it. A good *Depth of Penetration* is the first necessity for a good welded joint. Since only a small portion of the article can be maintained molten by the arc in this condition, it so happens that the filler material is always transferred from the electrode to this point and not to those surrounding portions of the article, which are not molten, as it cannot fuse with them, but will only stick to them. As was mentioned in the previous discussion on the arc, the cinematograph photographs of the arc taken by Hilpert and Thun have shown that the filler material is transferred in the arc in drops over the shortest path from the electrode to the article. The same direction, as is taken by a drop passing to the article, must therefore be given to the arc, that is, the shortest path between the electrode and the

article. It may be assumed this is usually impossible if the arc is held perpendicularly to the weld surface. Due to the magnetic lines of force, which are set up in the article by the discharge of current, the arc is disturbed, that is, it is subjected to the effect of a "*Blow*". This must be neutralized by the *Manipulation of the Electrode.* The most varied and contradictory views have been broadcast about this process, and consequently it has so happened that, even when dealing with the manipulation of the electrode, the most varied instruction is given. The experience of the Welding Research Laboratory, in which all the electric welders belonging to the State Railways have been trained, has yielded the following results.

Information about the "blow", to which the arc is subjected, may be obtained in the simplest manner, and the processes may most

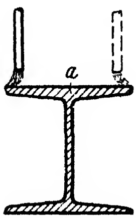


Fig. 110.—Illustration of the action of the arc

a, Connexion of positive pole

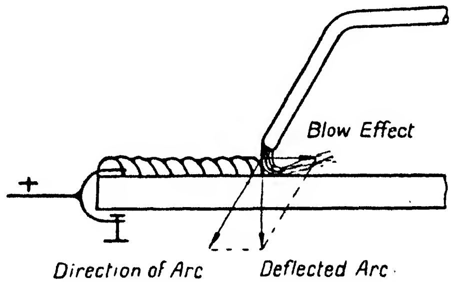


Fig. 111.—The way in which the electrode is held during arc welding

clearly be observed by guiding a long carbon arc over an I joist, situated on the welding bench in the manner shown in fig. 110. The connexion of the work to the positive pole is obtained through the welding bench, that is to say, as far as the upper flange is concerned, it lies in the middle, at point *a*. If the electrode, which is held vertical to the surface of the flange, is moved from left to right, it will be clearly seen that until the middle of the flange, that is the connecting point, has been reached the arc is "blown" out to the left without touching the point on the work which lies under the electrode. If the electrode is moved further (dotted position), the arc reverses to the opposite direction. Hence the arc is always "blown" away, in a direction away from the connexion to the work. By holding the electrode inclined as is shown in fig. 111, the arc may be compelled to take the shortest path to the work and to melt exactly the point, which the transferred filler material

touches, before it is disturbed by the " blow ". The bend in the electrode, which is shown in the figure, is only intended to facilitate the guiding of the electrode by the welder.

The magnitude of the effect of the " blow " varies with various plate thicknesses and decreases with the distance from the connexion to the article. Consequently no definite information can be given regarding the amount of inclination of the electrode.

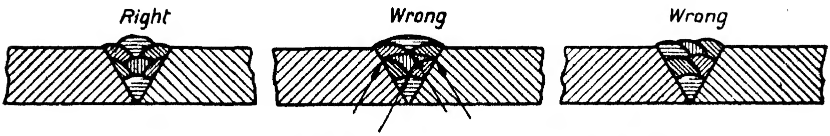
Further, it has been shown to be advantageous to weld in a direction away from the point of contact with the work, so that, from what has been previously stated, the electrode should be held inclined in the direction shown in fig. 111. With this direction of welding, the arc is " blown " over the open weld groove which is thus advantageously preheated. One may also weld in the reverse direction, i.e. towards the point of contact, but then the electrode must be inclined to a corresponding extent, so that the arc is compelled to assume a vertical direction. The weld, which has already been made, will now be brushed by the arc, and the former acquires a rusty brown covering of very minute beads of iron particles which are thrown out, and becomes very dirty in appearance. Consequently, it is preferable, so to select the current connexion to the work, that the welding is directed away from it, and if this cannot be done along the whole length of the weld, because of the type of construction, it is preferable to move the connexion. With long seams, it will be necessary to move the point of connexion now and again. Frequently the phenomenon occurs that, at a certain distance from the point of connexion, the arc becomes disturbed, flickers to and fro, and even goes out. This is probably due to eddy currents which are set up in the work. If the welder cannot control this phenomenon by successful manipulation of the electrode, the point of connexion must be moved nearer or put on the other side, and then the weld must be started again from the other end. This phenomenon has also been connected with unequal heating of the work. Attempts have been made to overcome it by heating the work or by preventing the conduction of heat by means of heat insulating backing pieces, and with thick sections this has proved to be of some advantage.

As regards the connexion of the article to the current supply, it should be noted that the parts which have to be welded should both be connected, so that the arc acts equally on both welded edges. If this cannot be obtained by means of a clamp, the connexion should be split. As a rule, the work is connected to the positive pole and the electrode to the negative pole of the current

supply, but there are exceptions in which the opposite procedure is adopted, and these will be discussed later.

As far as the manipulation of the electrode is concerned, the following points should be borne in mind. The arc should be kept as short as possible so that the absorption of oxygen and nitrogen from the air by the molten filler material, which is transferred in the arc, is made as difficult as possible, since the filler material has a great affinity for them. The absorption of nitrogen conduces to an appreciable extent to brittleness in the weld, and this will be dealt with in greater detail during the discussion on covered electrodes.

If a weld groove is to be filled up, as is the case with junction welding or in the welding of fractures, it is most suitable to select an electrode about $\frac{1}{16}$ to $\frac{1}{8}$ in. thick, even with thick plates, and to guide the arc in a straight line along the groove. In this way, excellent



Figs. 112–114.—Right and wrong multi-run welding using the arc

welding of the root of the groove is achieved. An oscillating to-and-fro movement, which is frequently recommended in this case, and also for fusion gas welding, is unnecessary. This movement is only made if the weld run does not fill the groove, and one has to weld in several runs. A circular movement of the electrode, as is frequently recommended, is inadvisable, because the arc passes over places which it has already touched; the seam will then be fused to some extent and the material burned.

If the groove is not filled up by one run, as in the welding of thick plates, a second is put down and if necessary further runs are added. Consequently, a fundamentally different method is adopted from that in fusion gas welding where the groove is, as a rule, filled up for the complete depth. Thicker electrodes are chosen for additional runs for various plate thicknesses, as shown on the previous page. Before a further run is put down, however, the previous ones must always be cleaned thoroughly with a wire brush, so that they are metallically clean and free from spatters. Special care is to be observed when covered electrodes are being used, since slag, which can only be removed with difficulty, lodges in cavities in the weld.

This slag does not come to the surface of the molten bath when fresh runs are put down. It is covered up and forms undesirable inclusions.

On the other hand, welding in several runs results in the normalizing of the weld. In the welding of each run the one which has been put down first, and which lies below it, is annealed and its structure is refined, so that its hardness is diminished. Annealing is, therefore, an advantage in multi-run junction welding, especially when high quality of the latter is required.

In addition, in these circumstances it should be noted that if more than two runs have to be put down near one another, one should always be put down, starting from one edge of the article, and only then should the middle run be added, as is shown in fig. 112. Sharp angles, such as may be seen from fig. 113, as shown by the arrows, are to be avoided. These are difficult to melt down and give rise to pockets of slag. Even with this arrangement, a joint between the runs, one below the other, is not so good as in the arrangement in fig. 112. The arrangement in fig. 114 is bad under any circumstances, since the edges of the angle of bevel are unequally heated.

Electrode moved along too quickly, or arc held too long

Fig. 115

Electrode moved along too slowly.

Fig. 116

Correctly Welded

Fig. 117

Welded with too low a current

Fig. 118

Figs. 115–118.—Sections through runs of weld with correct and incorrect welding

With skilful guidance of the electrode, a uniform run is obtained, just as if drop had been laid on drop. The regularity of the welding process is immediately upset as soon as irregularities in the guiding of the electrode occur due to unsteadiness of the hand or from other causes. If an arc is struck too long, a tendency which the beginner frequently has, since a long arc is easier to maintain and contact between the article and the electrode is easier to prevent, the filler material drops in large drops with vigorous spluttering, and this has the result of preventing adequate depth of penetration from being obtained. The drops do not always fall on the molten crater, but on spots of cold metal so that they do not weld. The weld has the appearance shown in section in fig. 115, whereas a good weld should have a section as shown in fig. 117. The arc

must therefore be kept as short as possible, if good penetration is to be obtained. As a general figure, the arc length should be about equal in thickness to that of the electrode.

If the electrode is moved forward too quickly, the same bad result is obtained as if the arc is held too long. In this instance the arc also does not bite sufficiently into the article. In addition, there is the danger that the crater will not be completely filled up by the metal which is melted down, and that cavities and inclusions of air, which reduce the elongation of the weld on fracture to a considerable extent, will occur. If, on the other hand, the arc is moved too slowly in the direction of welding, the molten crater will be over-filled with filler material. This overflows, and as is shown in section in fig. 116, it does not combine with the material at the edges since this is not sufficiently molten. At the same time, there is the danger that if the electrode is moved too slowly the base material will be over-heated and burned. Over-filling of the weld crater also occurs if welding is carried out with too low a current strength, when the depth of penetration is insufficient, as may be seen from the section in fig. 118.

In general, as far as welding faults are concerned, the same remarks as have already been made about fusion-gas welding apply. The driving out of the slag is very difficult, and for this purpose only the " blow " of the arc can be used. Only by practice and by correctly holding the electrode can a welder acquire the necessary skill. He must, at the same time, distinguish between the correct welding temperature from the brightness of the molten iron, and that resulting from discoloration caused by the floating slag. Consequently, working with covered electrodes, in which a larger quantity of slag is formed, is more difficult and requires greater experience than welding with bare electrodes. It should be mentioned here, that it is a mistake to supply beginners with covered electrodes on the assumption that, by this means, welding will be simplified, and that by using covered electrodes one can train new welders in a short time to replace those who have left. It is certainly easier to maintain the arc with covered electrodes, and it is of less importance when these are used whether the arc is kept short or long, but at the same time there is a greater danger of slag inclusions and of junction flaws from them, which can only be avoided by a welder who has already acquired experience.

Arc welding requires special skill if vertical seams or overhead seams have to be made, and if it cannot be carried out in the hori-

zontal plane. At the same time, the difficulty is not so great as with fusion-gas welding, because there are smaller quantities of molten material, which can be put down in the form of drops, by making contact with the article and the electrode from time to time, in such a way that they are attracted by the action of surface voltage, in accordance with our recent hypothesis. In these circumstances the polarity is reversed, that is, the positive pole is attached to the electrode.

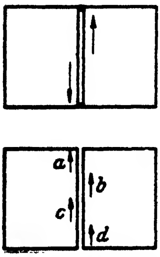
In building-up welding, it is good practice to proceed as in junction welding. In general, the same remarks which were made about building-up welding employing the gas welding process apply. Preheating of the article should be carried out if the article is subjected to continuous stresses or if it has wall thicknesses which are not uniform. Interrupted welding, with the article in the cold state so as to avoid overheating of the latter and for the purpose of rendering heat treatment unnecessary, has not proved sufficient to avoid contraction cracks.

In order to obtain a surface which is resistant to abrasion, high carbon or suitable alloyed welding wires are used. In building-up welding of this kind, multi-run welding is, however, not an advantage, as it is in junction welding, but a drawback, since the normalizing of the lower layer has the result that only the top layer possesses the desired hardness, whereas the lower ones have lost their hardness. Consequently the resistance to abrasion of the article is always increased if wide, thick runs with heavy electrodes are put down from the start.

Finally, when making welds, special attention should be given to the avoidance of *Stresses* and *Distortions*, in so far as this is possible. In this respect, as has already been noticed, arc welding is intrinsically superior to gas welding, since the heating of the article lies within much smaller limits. At the same time, even this small heating effect may be dangerous and lead to considerable stresses. As a contrast to gas welding, however, arc welding provides a very effective means of keeping the stresses within permissible limits.* Whereas in gas welding the weld groove must generally be welded continuously from one end to the other, in arc welding step welding may be done, that is, the weld may be interrupted before the heating and the elongation of the plate becomes too great, and the weld may be started at another place. If one wished to employ the same process

* Lottmann, "Notes on Contractions, Stresses and Distortions in Arc Welding", *Schmelzschweissung*, Vol. 8 (1929), p. 154.

with gas welding, the space where the welding was interrupted would be subjected twice to a large heating effect by the flame. In this respect, it should be noticed that, always when a weld is started in gas welding, as well as when a point is remelted, a large quantity of heat and time are required, and hence the danger of burning is increased.



Figs. 119 and 120. — Step by step welding.

Step welding may be done, for example, in the way shown in fig. 119, in which the ends of the seam are first tacked and then, starting from the middle, both sides are welded. Compression and tensile stresses result, which balance one another and prevent greater stresses from being set up, whereas in continuous welding in one direction, tensile stresses alone occur, and these may be very large.

Staggered and *interrupted* welding, as shown in fig. 120, gives better results still. The first run is started at *a*, the rest at *b*, *c* and *d*. The alternating tensile and compressive stresses which are set up may be kept so small by this means that a seam which is almost completely free from stress may be made. Distortion of the plate, due to contraction of the molten filler material, may be met by giving a definite angle of set to the seam in the two plates, which have to be joined before welding. In this way, distortion draws the plates together in the same plane. With heavy cross sections it is advisable to use the X-seam if distortion is feared, and in this way, the distorting forces on each side equalize one another. During the second welding the unfavourable phenomena which accompany the first are eliminated.

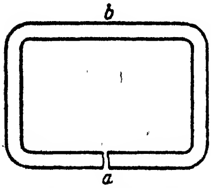


Fig. 121.—The avoidance of distortion when welding closed frames.

In gas welding, distortion caused by welding, due to elongations set up by the heat, may be frequently avoided by heating the point directly opposite to the weld zone. The frame which is shown in fig. 121 will serve as an example. During welding, because of the elongation, in addition to the contraction during cooling, a bending moment will be set up in the upper corner, which may result in a fracture. If the point *b* is so heated that the upper side of the frame receives the same elongation as the lower point at *c*, this danger, which is due to welding, will be avoided.

Wherever welds are situated symmetrically, the same end may be achieved by welding the two simultaneously.

Further methods of guarding against stresses are those associated with the avoidance of excessive heating, such as welding with interruptions, the procedure being to cease welding as soon as the material adjacent to the weld zone exceeds hand heat or by welding with cooling water or with cooling metals.

The examples which have been given do not exhaust all cases. They may, however, show how, by consideration of the way in which the weld is to be made, the difficulties caused by heat effects may often be eliminated, or at least modified.

Finally, contraction stresses which have been set up may be diminished, to some extent, by hammering after welding at red heat, by which means the point of contraction is elongated to some extent. Hammering, however, is only to be recommended when forgeable electrodes are used, and then there is an improvement in quality. In no case must hammering be done at blue heat, since just the opposite of an improvement will take place, namely, a breaking up of the structure. When ordinary electrodes are used, hammering in general does not result in an improvement in quality, nor does subsequent annealing. Pores may only be partially sealed.

The provision and supply of *Welding Jigs* has led to considerable simplifications and savings in workshops, and also in workshops where work of the same kind or in large quantities has frequently to be carried out. Suitable locating jigs, which make it possible to position the parts which are to be welded, quickly and securely, without first having to fit them carefully together, may be made without difficulty for various types of work. Rollers and turntables further facilitate the handling of unwieldy members, which have frequently to be turned or moved during manufacture if work in the vertical or overhead position is to be avoided.

Attempts to simplify, speed-up, and to improve the work as much as possible, as well as to limit the human element, have further led to the construction of automatic welding machines. To-day, in gas welding, they are primarily intended for longitudinal seams, and offer a considerable number of advantages, especially in the welding of flat plates, for example, casings. In addition, there are also longitudinal welding machines for special purposes as, for example, for the welding of cylindrical vessels such as drums, &c. There are other machines for flanged seams, tube welding, circumferential seam welding, and for the welding on of end covers, &c.*

* Berthold, "Recent Types of Autogenous Welding Machines", *Technisches Zentralblatt*, Vol. 39 (1929), p. 58.

For thicker plates, which can only be welded when the burner describes an oscillating motion during its travel, as in hand welding, machines have been built with this to-and-fro motion of the torch. As these torches are subjected to heavy loads they are, as a rule, water cooled.

In arc welding also, the construction of *Automatic Welding Machines* has been taken up. In this field, there are types which work with the simple metallic arc as well as those which employ the carbon arc. The former appeared first on the market. They serve the purpose of welding worn tyres and guide blocks. There are also machines built for repair work as well as for junction welding. In this field we have the mass production of back axle casings, pipes, and other similar articles of the same shape.

With these machines the quality of the product is dependent, to a high degree, on the property of the wire. The feed is controlled by the conditions obtaining in the arc. If the arc is too long, the feed is speeded up by means of a suitable device, and conversely if the arc is too short it is speeded down or temporarily stopped. Consequently, the wire must have absolutely constant properties. Wire which is too soft bends easily and jams. Wire which is too hard locks during feeding. In both cases there are faulty spots which must be repaired by hand.

Recently the development of automatic electric welding machines has appeared to be more in the direction of the construction of machines with a carbon arc, with which very much higher welding speeds may be obtained. They are primarily suitable for seams which may be welded without filler material, as well as for the welding of thin plates on mass-production work. Welding machines which have such a high output as these are assured of a considerable future for various purposes, such as the manufacture of new sections for steel construction and bridges provided they are constructed with an automatic feed for the wire, since the rolled sections which are available cannot in most cases be economically machined down.

After having discussed, in the previous pages, the general principles relating to fusion welding, in respect of the various metals, the choice of the process, as well as the preparation and the making of the weld, points which should be observed because of the special properties of various metals will be discussed in greater detail in the following pages.

The Welding of Steel

The most important alloying constituent of iron is carbon. Even small modifications in its content cause a considerable variation in its behaviour. Iron, with a carbon content of ·05 to 1·7 per cent is called steel, iron with a carbon content of about 2 to 5 per cent cast iron. During heating, steel goes from the solid then into the plastic, and finally into the molten condition. Cast iron, which is rich in carbon, passes immediately into the molten state. Low carbon steel is soft and easily forged. With increasing carbon content, the strength of the steel increases, but it can only be welded with difficulty. Consequently, it is absolutely necessary for the welder to be acquainted with the behaviour of steel of various carbon contents, at high temperatures. These properties are shown in the *Iron Carbon Diagram* (fig. 122) which has been drawn up by the Verein deutscher Eisenhüttenleute (The Association of German Steel Manufacturers), and they will be briefly discussed.

In fig. 122 the carbon content or iron carbide is plotted on the horizontal axis (abscissa) and the temperature on the vertical axis (ordinate). Depending on the composition, the melting-point of the iron passes from the point F, 2795° F. (1535° C.), which is the freezing-point of chemically pure iron, to the line F, G, E, H, the so-called liquid line, whereas the line F, D, E, K, shows the upper limit for solid iron at the change point of solid iron into the plastic state. It has been shown that the duration of the plastic state decreases with increasing carbon content until at point E with 4·29 per cent carbon, the change into the plastic state coincides with the molten state, that is to say, the iron passes instantaneously into the fluid state.

In addition, the points 2555° F. (1405° C.), A 1660° F. (900° C.), 1410° F. (768° C.), and 1283° F. (695° C.), at which a change in the crystal structure of pure iron takes place, on heating, are worthy of note. The so-called α modification, which lies between 768° C. and 695° C., and the γ modification between 1405° C. and 900° C., are especially important. In γ iron mixed crystals of pure iron (Ferrite) and iron carbide (Fe_3C) have formed, whereas in α iron, ferrite and iron carbide may separate out independently. The most important point is that only α iron possesses magnetic properties, whereas in β iron, which lies between the modifications already mentioned, the magnetism has disappeared. δ iron is of no practical importance.

Point D in fig. 122, which separates steel from cast iron, is of considerable importance. It indicates the maximum content of iron carbide which can be taken up from the mixed crystals in the heated state. With higher carbon contents, the residue which has been saturated with carbon will always solidify with a content of 4·3 per cent carbon.

In addition, for all bodies there is an optimum state of solution, provided that they are soluble in one another. When this is reached one gets the eutechtic alloy which occurs at the same place on the figure as the minimum melting- or freezing-point. In liquid solution, at the point E, it is termed the Eutectic, in solid solution at the point C, the Eutectoid. Iron in this state is termed eutectoid. With decreasing carbon content there is an excess of Ferrite, with increasing carbon content an excess of cementite. The iron, in the first case, is termed the sub-eutectoid, in the latter, the super- or hyper-eutectoid.

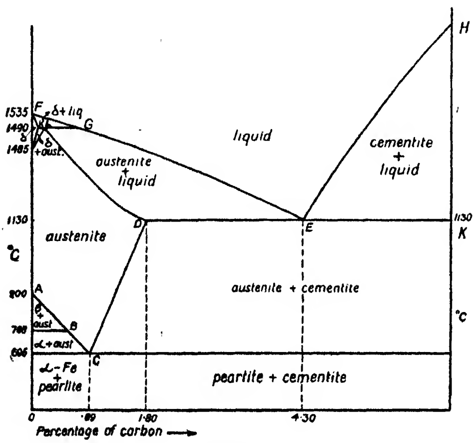


Fig. 122

For the welding of steel the following is important. By suitably rapid cooling, or by satisfactory alloying with manganese or chromium, one may ensure that the heated steel which has gone over to the γ modification retains its structure after cooling even at room temperature, by which ductility and ease of working are gained. At the same time, this condition manifests itself by the inability of the steel to be magnetized. Such steels are called Austenitic steels. They are easily welded. By rèducing the velocity of cooling of a steel, which has been heated above the critical point, a new structure is obtained called Martensite. This is extraordinarily brittle, and is prone to fracture during welding. Due to the rapid cooling, the possibility of the steel decomposing into its original structure of Ferrite and Pearlite, or Pearlite and Cementite, is partially prevented. The structure had a needle-like appearance.

These processes have acquired considerable importance in welding technology, since, as has already been stated, alloying with nickel,

manganese, chromium and tungsten, where the nickel and manganese behave as alloying constituents like carbon, chromium and tungsten, greatly assists the translation of the pearlitic steel into Martensite and Austenite.* By means of these alloys, the strength of the steel is considerably increased on the one hand, and on the other, the production of stainless steels is dependent upon them. The latter are used almost exclusively in the chemical industry, and the former to an increasing extent in the structure of steel framed buildings and bridges. The welding engineer is considerably interested in the weldability of these steels. There is again the requirement that, as far as possible, austenitic steels must be used. For martensitic steels as, for example, stainless chromium steel, fusion-gas welding is to be preferred since, with this process, cooling is delayed. For austenitic steels, electric welding may be satisfactorily used, since the ductility is retained on cooling. It should be noted, however, that with these steels, hard spots occur during the critical range at a critical temperature of 1100 to 1300° F. (600 to 700° C.). These may be removed by heating to a high temperature, and cooling quickly or slowly depending on the alloy.

The conditions during welding are complicated by the presence of other alloying constituents among which must be reckoned manganese, silicon, sulphur, and phosphorus. One speaks of binary, ternary, quaternary and complex alloys. In addition, nickel, chromium, vanadium, tungsten, molybdenum, &c., are frequently added to steel, either individually or severally, in order to improve its properties. In this way, the strength is influenced very favourably. Moreover, by the addition of such alloying constituents, the weldability is, to a certain extent, guaranteed. We must not omit to mention tin, aluminium, arsenic and titanium, which, above a definite content, considerably reduce the weldability of steel. Sulphur and phosphorus must be counted among the undesirable constituents of iron. Individually they should not exceed ·04 per cent, and together not more than ·06 per cent. Between the usual limits, the weldability is not adversely affected by phosphorus, but there is the possibility of cold shortness. It is occasionally added to cast iron to produce a free flowing iron. In this respect, sulphur works in the opposite direction. It is very dangerous where stresses occur. It also produces red shortness, and in the red heat favours the absorption of oxygen. The absorption

* Rapatz, "The Welding of Alloy Steels", *Technisches Zentralblatt*, Vol. 39 (1929), p. 430.

of gases is undesirable in all cases where good quality welding is desired. Consequently, the effect of oxygen and hydrogen must be avoided as far as possible, since they are responsible for brittleness and a tendency to fracture. Too high a concentration of oxygen can even lead to fatigue fractures, whereas too high a content of hydrogen results in corrosion brittleness, and this should be borne in mind. The absorption of nitrogen leads to a porous structure. Segregations, slag inclusions, and cavities are signs of weakness in iron, and should therefore be avoided. Overheating and burning, as well as fatiguing, also affects the properties of the material adversely. Stresses and fatigue effects may be restricted by annealing.

Along with references to the properties of the steel which has to be welded and the correct choice of the welding process, which has already been indicated, the use of a suitable *Filler Material* is of primary importance. Only then is it possible to obtain an intimate union between the filler material and the article, and ensure that the structure of the weld, in respect of its technical properties and chemical composition is, as far as possible, similar to the structure of the base material. In this respect, the conditions obtaining in electric welding, due to the processes in the arc, are very much more difficult than those in fusion-gas welding. Because the importance of a suitable filler material was not originally recognized in welding engineering, and as, initially, attempts were made to weld with all types of wires, such as mattress and fencing wire, an explanation of these early mistakes is apparent, especially in the field of electric welding. Even up to a few years ago, the view was held that the chemical composition (analysis) of the wire was all-important, and that the same wires could be used for both gas welding and electric welding, with equal success. Moreover, opinion was sharply divided as to whether electric welding was more satisfactory with bare or covered wires. To-day this attitude has completely changed and has resulted in a considerable improvement in filler materials, a process which does not appear as if it would be concluded for some time. The attempt to weld high alloy steels has contributed not the least to a large number of filler rods which are specially and accurately prepared to suit the original material, depending on the type of the process and the kind of material which has to be welded. Because of the wide variations which occur in the high alloy steels, definite specifications for the composition of suitable filler wires cannot be given. The manufacturers of the steels, there-

fore, always offer suitable and tested filler wires for their various types of steels.

The purchaser of welding wire is advised on acceptance of the wire to convince himself of its quality and usability. For this purpose an investigation and practical test of the steel by means of a welding test are advisable. The wire should then be judged on its external appearance.

Externally the wire must be free from scale, oil and rust. In order to protect it from rusting during storage it may be coppered. In addition to having a smooth, flawless surface, the wire should have a round regular section. Annealed or unannealed wires are absolutely identical, for hand welding, if they have the same chemical composition. For automatic welding, annealed wire is unsuitable because it easily jams during feeding. Nevertheless the gas welder prefers to use a good flexible wire, that is an annealed wire, whereas the electric welder prefers an unannealed wire which can be broken. The so-called wood charcoal welding wire is of no special importance, as this usually is only an ordinary wire which has been annealed in wood charcoal.

The wire should then be tested with reference to its chemical composition. This depends on the welding process and on the purpose for which it is to be used. As has been previously mentioned, the same wires cannot be used for fusion gas welding as for electric welding. Moreover, in many cases, an inexpensive wire is suitable, whereas for quality welding on highly stressed members severer requirements must be imposed on the wire. In certain circumstances, especially where alternating stresses are to be expected, wires must be used which give a forgeable weld. In addition the chemical composition must be different for built up welds, and for welds which are required to give varying hardnesses of the built-up layer on materials which are low or high in carbon.

Bearing these points in mind, the following figures may be recommended for the chemical composition of bare wire.

For a wire which gives a soft weld with gas welding, and has a tensile strength of about 80 per cent of the base material, we have C up to 0·12 per cent, Mn 0·3–0·6 per cent, Si 0·08–0·25 per cent, P and S each not greater than 0·03 per cent. Greater hardness and a tensile strength of 100 per cent of the base material may be expected from a wire with C 0·15–0·25 per cent, Mn 0·6–1·0 per cent, Si about 0·25 per cent, P and S as before.

For arc welding, the values are as follows: C up to 0·12 per cent,

Mn 0·3 to 0·6 per cent, Si 0·1 per cent, and for high quality wire, C up to 0·12 per cent, Mn 0·5 per cent, Si 0·1 per cent, and in both cases P and S 0·03 per cent. maximum.

For building-up welding, using fusion-gas welding and a mild wire, the same wire is used as for simple junction welding. For a harder surface a wire with C 0·5 to 0·7 per cent, Mn 0·5 to 0·8 per cent, Si up to 0·15 per cent is used, whereas for arc welding a wire is used similar to the high quality wire for junction arc welding. For soft welds, a wire similar to the high grade wire for fusion gas welding is employed. For harder welds, and especially hard welds to resist abrasion, a wire with C 0·9 to 1·1 per cent, Mn 0·15 to 0·5 per cent, Si up to 0·25 per cent is recommended.

It is important that the silicon content should not be exceeded, since protection is thereby afforded to the purchaser that basic steel, which is usually very irregular in composition, is not used for the manufacture of the wire, but that the wire is made from good Siemens-Martin or steel from the electric furnace.

If the wire is satisfactory in respect of chemical composition, a weld test should be carried out, in addition to the above analysis. In point of fact, it frequently happens in welding that wires which have an absolutely similar chemical composition behave very differently. In this test the flow and the loss due to burning should be ascertained. The filler material should flow easily and regularly and should only splutter slightly. In gas welding it should only froth to a small extent and form little slag. Filler materials for overhead and vertical welding should possess an adequate " climbing ability ". In order to test this " climbing ability " the wire should be melted down on a vertical surface from bottom to top, and this is best done by describing a circle of at least 2½ in. diameter.

In general, it may be noted that a wire which contains gas inclusions is no use for electric welding because it gives rise to high spluttering losses, whereas it may quite well be used for fusion gas welding. Conversely, a wire which gives rise to an increase in slag is unsuitable for fusion gas welding, whereas in certain circumstances it may even be desirable in electric welding.

In addition, a mechanical test of quality of the welded specimen is advisable. The tensile strength of the weld seam is determined in the usual way by means of a tensile test, its elongation by a bend test, more details of which will be discussed in a later section. In order to test the forgeability, the specimen should be forged down from the middle outwards at a forging temperature not less than

1700° F. (930° C.), to half the thickness of the specimen, so that the weld seam lies approximately in the middle of the length of the test piece. The forged down portion of the specimen should then be capable of being twisted at a forging temperature of 680° F. (360° C.) without showing fracture.

Since wires of absolutely similar chemical composition frequently behave differently during welding tests, this may easily be due to the condition of the surface and the process of manufacture of the wire. In wires which have to be used in arc welding we certainly have to deal with the presence of traces of elements in the steel which cannot be determined by analysis, but which exercise a definite effect on its behaviour. We have already discussed these in the section on " The Arc ". In addition to the theoretical analysis which was discussed, practical experience supports this view.

Based on the fact that wrought iron, which was previously used, but to-day has been abandoned because of its irregular properties, had excellent weldability, the firm, Böhler, has come to the conclusion that the weldability of steel may be considerably affected by the presence of non-metallic constituents as they occur in wrought iron.* Consequently they have put a wire on the market in which the non-metallic constituents of this kind are distributed regularly and in tested amounts in the middle of the wire. The wire is known under the name of " Seelendraht " (Core wire).

Very high quality welds, which have a high ductility and forgeability, may be made with this wire. It is unsuitable for gas welding. The same success may be achieved when these non-metallic constituents, which fuse and vaporize in the arc and spread over the article to some extent, are supplied in the form of a covering for the wire. The use of covered electrodes in electric welding, in the place of the bare electrodes, which have previously been discussed, has been known for some time, but initially a different object was aimed at.

One differentiates between lightly-covered or dipped, and heavy-covered or wrapped (coated) electrodes. The manufacture of dipped electrodes is carried out by brushing the wire or dipping it in a material of a definite composition which is mixed to a paste with a binding material such as waterglass, &c. The composition of these pastes is always treated as a manufacturing secret. As a rule, the coverings principally contain alkaline silicates and ferro-silicon and substances containing borax. Recently they have been enriched with

* Rapatz, " Metallurgical Observations on Fusion Welding ", *Stahl und Eisen*, Vol. 51 (1931), p. 245.

various alloying particles which are stated to be transferred to the weld.

Heavy covered electrodes either have a wrapping of blue asbestos rope about $\frac{1}{16}$ in. thick, under which is placed an aluminium wire (electrodes of the Quasi-arc Co.) or a wrapping of white asbestos or dipped string to which alloy constituents are added (electrodes of the Murex Welding Processes, Ltd.).

At the present time there are considerable differences of opinion concerning the suitability of covered electrodes. Whereas England, Switzerland, Belgium, Holland, and Australia have gone over almost entirely to the use of covered electrodes, in Germany and America bare electrodes are usually preferred, and covered electrodes are only used in individual or special cases. Consequently, the advantages and disadvantages of covered electrodes will be discussed more closely.

It must definitely be agreed that the covering, which is vaporized in the arc and then forms a mantle of gas around it, offers the following advantages:

1. The arc is easier to maintain. Welding with the unstable alternating current arc is practicably only possible with the use of covered electrodes.

2. To some extent, the covering prevents the ingress of oxygen and nitrogen from the air to the finely divided filler material, which is being transferred in the arc.

3. The covering forms a slag on the weld which protects the bath from the effects of gas from the air.

4. Heat is required for vaporizing the covering, and this heat is removed from the electrode during the melting of the filler material. The fusion process is therefore delayed, and time is gained for fusing the base material. To what degree this is the case with light and heavy covered electrodes is shown by the oscillograms taken by Bung, which have already been shown in figs. 37 to 39.*

5. Cooling is delayed because of the slag covering the molten zone. The result is a finer structure of the weld zone with covered electrodes as compared with bare electrodes, and consequently a higher ductility of the weld. At the same time greater stresses are set up.

6. It has been shown that by the addition of definite alloying constituents, chiefly manganese, nickel, &c., the weld may be

* Bung, "Tests with Oscillograph in order to investigate the Processes in Electric Welding Arc", *Elektrotechnik und Maschinenbau*, Vol. 26 (1928), p. 2.

enriched with these and hence improved. Consequently suitable electrodes may be made for various purposes.

At the same time, the heavy slag formation is to be offset against this advantage of covered electrodes, and with heavy covered electrodes this slag formation is very great. The welder has to have special skill in order to follow the fusion process closely, since his observation is considerably impaired by the slag, and furthermore he has continually to drive out the accumulating slag. Consequently, very light runs must be put down.

Numerous runs, however, result in greater contraction stresses, and these are intensified because covered electrodes result in greater heating of the weld seam and the adjacent material than bare electrodes. From photographed oscillograms it has been satisfacfactorily established that the covering causes a retardation of the speed of fusion of the electrode. Whereas with this electrode only three transfers of drops in half a second were registered, thirteen transfers were counted with bare electrodes during the same period of time. The drops with the covered electrode were 3–4 times as big as those with the bare electrode. The transfer of drops in itself only occupies a very small proportion of the total time of the welding process. The ratio between the drop transfer and the preheating period which lies between two transfers, amounts with covered electrodes, to about 1 : 11·5. With bare electrodes, however, it amounts to only 1 : 2·4, so that without further comment the more intense heating of the article may be explained.

In addition, recent experiments in the Technical Welding Research Laboratory have shown that it was not possible for our welders, who had been trained on bare electrodes, to control the slag even when depositing a single run, if the plates had to be welded in an absolutely horizontal position. It was only when a definite slope was given to the plates, so that the slag could flow downwards, that good results were obtained. Consequently, there is no difficulty in welding vertical seams with covered electrodes, but, on the other hand, there is considerable difficulty in making the horizontal seams overhead. For this purpose, a weld angle of at least 120° must be chosen, so as to make it possible to drive out the slag at the sides, and this is neither an advantage for the quality nor for the cost of the work. On the other hand, the welders could make overhead welds with bare electrodes much more easily. It is true that they did not attain the quality of horizontal or vertical seams, but at the same time, they were always better than welds with covered elec-

trodes. Special mention is made of this matter, because previously it has always been considered that overhead welding could only be carried out with covered electrodes.

It must be admitted, however, that welders who have been specially trained on covered electrodes would get better results with them than our average welders who have been trained principally on bare electrodes.

If it is further borne in mind that covered electrodes are as much as twice to ten times as expensive as bare electrodes, depending on the process of manufacture, so that the excess cost cannot be balanced, and further, that higher welding speeds cannot be obtained, especially when welding with numerous runs where the cleaning of the lower run occupies a considerable amount of time, it is questionable whether their advantages are so great as to justify their use. It should be mentioned that it is possible for a skilled welder, even with bare electrodes, by holding a short arc, to keep absorption of oxygen and nitrogen from the air within moderate harmless limits, and that to-day there are bare electrodes which make it possible to produce welds having high ductility and forgeability.

Consequently in the writer's opinion the necessity of using covered wires did not exist so long as we were dealing with the manufacture of articles which were only subjected to normal tensile, compressive or bending stresses. To-day, where welding has been applied to constructions which are subjected to alternating or impact stresses or where the phenomenon of fatigue is encountered, conditions are different, and consequently a high notch impact value of the weld seam is necessary. This cannot be obtained either with bare electrodes or with lightly covered ones. As a rule it seldom reaches a value greater than 10 per cent of the original steel, and is therefore so small that it can be neglected in calculations. Success cannot be achieved by subsequent treatment by annealing; on the contrary by this method the notch impact strength of the weld is often reduced still further. Consequently one had to be satisfied with this as long as there was no suitable electrode which fulfilled the final requirements for the quality of a weld, namely, a high notch impact value.

Success has been achieved in this direction for some time with heavy coated or wrapped electrodes of which the Quasi-arc electrode may be mentioned as an example. They are not only expensive to buy, as was previously pointed out, but they are expensive to put down since, because of the danger of slag, they necessitate the

putting down of very thin runs and require very careful work. Quite recently, however, a new covered electrode has been put on the market in Germany by the firm Pintsch which leads one to expect that there will be a complete change in high-grade welding such as boiler welding and the welding of bridges and building constructions.* The most careful determination of the metallurgical properties of the filler material and the covering, on the one hand, and the base material, on the other hand, was made. In addition, subsequent heat treatment, which was previously unknown, was carried out on the welding wire after the rolling process. By this means, success has been achieved in the manufacture of an electrode which gives welds which can no longer be distinguished metallurgically from the parent metal, as is amply proved by photographs of etched sections. At the same time, the weld has the same ductility and strength as the parent metal and possesses a notch impact value (Charpy) of 560 ft. lb./in.^{2} in the unannealed, and about 845 ft. lb./in.^{2} in the annealed condition. Moreover, special skill on the part of the welder is not necessary, and hence a totally unexpected advance would appear to have been made in the development of the electrode, a development which has not yet been concluded. The goal of this development corresponds to the ability to make a completely homogeneous weld. The final goal will only have been reached when perfect welds can be made with electrodes of this type in any position, both vertically as well as overhead, and this is not the case to-day, since previous tests were only successful in the welding of horizontal or slightly inclined seams.

In addition, it should be mentioned that with direct current welding, it is by no means unimportant whether the electrode is connected to the positive or the negative pole of the welding current circuit. When welding with steel of low carbon content, it has proved satisfactory to connect the electrode to the negative pole. Because of the temperature difference between the positive and negative pole, better fusion of the base metal and consequently improved penetration are obtained. The same is true with wire having non-metallic inclusions for which gentle fusion and penetration of the negative pole are necessary, whereas in welding with the positive pole, they exert a harmful effect.

When steel has a higher content, whether of carbon or of metallic alloying additions, the conditions are changed. The wire burns

* *Zeitschrift des Vereines deutscher Ingenieure*, Vol. 76 (1932), No. 21, p. 497.

irregularly and the penetration is less if the electrode is connected to the negative pole. On the other hand, the fusion of bare wire with a high carbon content or a high alloy steel is relatively quiet at the positive pole. The penetration, however, is never so great as negative pole welding with low carbon steel. It is, however, of no great importance, since steels with a higher carbon content are always exclusively used for building-up welding, in which good penetration is not so necessary as in junction welding.

With covered wire, the conditions are similar. Wire with a light covering may generally be welded better at the negative pole, wire with a heavy covering must be connected to the positive pole, in order to obtain good penetration. The cause of this phenomenon has only partially been explained.

The Welding of Cast Iron, Cast Steel and Malleable Cast Iron

General.—Cast iron welding is usually limited to repair work. It is used for the repair of broken or fractured castings as well as for the filling up of faulty spots or of worn objects, and for the elimination of faults in the appearance of an article.

As has already been mentioned, cast iron is an iron rich in carbon, which, during heating, passes over from the solid state immediately into the liquid state. Therefore it can only be welded by fusion welding processes. The carbon, however, in grey cast iron is not chemically combined, as in steel, but partially separated as pure free graphite. The softness of cast iron and its capacity for being worked depend on this separation of the graphite, as cast iron, in itself, is brittle and hard. The separation of graphite is aided by the silicon content of the iron, but at the same time to a large extent by the slow cooling of the molten iron. A high graphite and silicon content is therefore a condition for the softness of cast iron.

These two valuable constituents disappear during welding, by combustion both in the welding flame and more so in the arc. In addition, unless special precautions are taken, the weld solidifies much more quickly than molten iron does during the casting of cast iron articles. Consequently, in the welding of cast iron, it is easy to get very hard weld spots which cannot be worked with any turning tool and which render a weld, which is otherwise satisfactory, unfit for service. The means of preventing this lie in the use of a material with a high carbon content and a high silicon content, and in the slow cooling of the welded article in sand or ashes. In addition,

welding fluxes are of advantage. Frequently a second torch is used for heating purposes.

If additional stresses are set up, due to excessive heating during welding and consequent rapid cooling, in a casting which has already been subjected to stress as a rule during its manufacture, these lead to cracks and fractures which in certain circumstances are worse than those which have to be repaired. A method of preventing additional stresses lies in heat treatment. It consists in heating up the article slowly to red heat before welding, welding in this condition, and taking precautions to ensure slow cooling. A further difficulty in welding is excessive shrinkage. If heating is employed, the process is termed " *Hot Welding* ", otherwise it is called " *Cold Welding* ".

With both processes, gas welding as well as arc welding may be used.

The Cold Welding of Cast Iron.—Since, during welding, the gas flame exercises a very great heating effect on the work in the neighbourhood of the weld zone, *Gas Welding* is seldom suitable for the cold welding of castings, and is in no case suitable for the welding of highly stressed articles. It should be mentioned that, due to the low heat conductivity of the graphite which is present in the cast iron, the weld easily becomes porous and blistered. In addition, the absorption of oxygen and nitrogen from the air and from the flame leads to the formation of small gas bubbles in the weld. Good fusion and intimate puddling in the fused bath is necessary in order to drive out these gas bubbles and avoid pores.

Even if the welding of cast iron with the welding torch is not easy for these reasons, the difficulties are increased by rapid cooling after welding as this results in hard spots, especially at the transition zone between the weld and the base material, due to the prevention of the formation of sufficient graphite. It is therefore advisable, after welding, to allow the flame to play on the weld zone for a few seconds and to remove the torch by degrees in order to delay cooling.

In this process, the welding equipment is the same as that in the gas welding of steel. Cast iron, however, is used as a filler material. Since cast iron, unlike wrought iron, does not pass temporarily into the plastic state during heating, but suddenly becomes fluid, it follows that castings can only be welded by this process in the horizontal position, since otherwise the molten iron flows away. This factor also makes work more difficult, since the parts must be dis-

mantled and frequently turned if the damage cannot be repaired from one side.

All this goes to show that, from technical and economical reasons, cold welding with the gas flame is only advisable for such fractured, cracked, or porous castings, which because of their shape are free to expand during welding in all directions. Such castings are usually those like levers, bearing housings, as well as pulley wheels and pinions of small size. Such articles, as a rule, do not require any special preparation apart from metallic cleaning. At the most, if a deep fracture is present, it is only necessary that the weld zone should be cut out and enlarged, as in the welding of steel, so as to make it possible to build up the weld from the root. The welding process is carried out in such a way that the weld zone is well fused and the filler material is added to the molten bath, which is formed, during which time a brisk stirring should take place. A point of difference from the welding of steel is that, during the gas welding of cast iron, a welding flux must be used in order to produce a low melting slag which combines with oxygen and this should rise to the surface of the molten bath and should be removed. In this way, the melting-point of the oxide is simultaneously reduced and the weld is covered by a protective skin. The welding flux is added to the weld by dipping the end of the hot rod into it, or on large welds by scattering it lightly over the weld.

Electric Cold Welding has acquired a sound position in cast iron welding due largely to the fact that it is the easiest and cheapest method for repairing castings. At the same time the value of this welding process is small.

As in the welding of steel, one usually welds with Slavianoff's process, using steel electrodes. Covered electrodes are to be preferred. The diameter of the electrode and the current strength are fixed according to the size of the casting. With direct current, the positive pole is connected to the electrode, as this is more difficult to melt than the casting. It is impossible to use cast iron as a filler material in this process, since the cast iron rod flows in large drops before the article has been melted, so that fusion with the latter is impossible.

Welding with a steel electrode gives a considerable advantage to electric cold welding over the other processes for welding cast iron, since, provided that the faulty place is accessible, it is possible to weld the parts, which have to be repaired, in situ without dismantling the machine, &c., and this can be done in any position either verti-

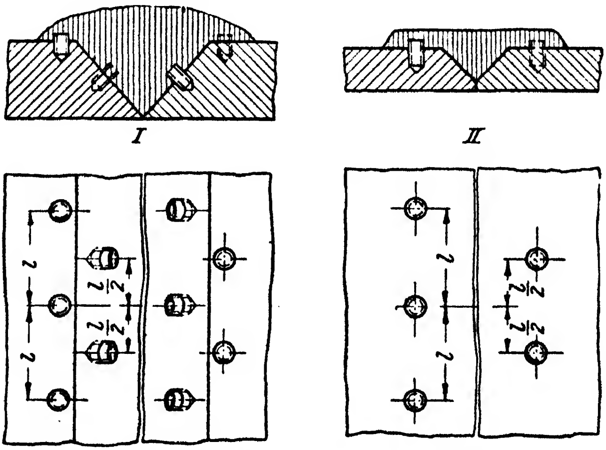
cally or overhead. On the other hand there is, however, the great drawback that in the welding of steel and cast iron, an intimate joint can never be obtained, and consequently there are frequently badly joined spots. In addition, the transition zone between the weld and the article is usually hard, since solidification of the weld takes place too quickly and in electric cold welding there are no methods of delaying the solidification process. Moreover in this process so-called hard white pig iron is formed, due usually to the insufficient separation of graphite and, because of the use of steel electrodes, steel of excessive hardness is also present. These disadvantages may be clearly seen in the etched photographs in fig. 123. This process is therefore unsuitable for articles which have to be tight or which are highly stressed. It is also unsuitable for articles which have to be machined over the weld, and especially so if the weld is situated on a surface which is subjected to heavy wear through friction during service, as is the case, for example, on the inner wall of a cylinder. The surface will be irregularly worn, so that the weld will soon stand proud and cause fracture of the piston. Moreover such articles cannot be subjected to changes in temperature on account of unequal expansion.

Fig. 123.—Micro-photograph of an electric cast-iron cold weld

As in the welding of steel, the casting is so prepared that a V-shaped groove is formed by cutting out the fracture or by bevelling the edges of the broken article. It is inadvisable simply to fill this groove completely with filler material along its length. A weld joint of this type would have an extraordinarily short life. Even with small stresses the weld will come away from the article, and in certain circumstances a blow from a hammer or a chisel is sufficient. One is therefore compelled to adopt a rather troublesome precaution, which takes a considerable time, in order to increase the life. This consists of inserting plugs or studs in the edges of the fracture opposite one another. These are welded in and usually form the only junction between the weld and the article. When these steps are taken, the section of the article should not be weakened too much, but the thickness must be the governing factor. Figs. 124–127 give an example of the arrangement of studs used with a heavy and with a light section. The broken pieces shown in fig. 128, from an article welded in this way, show that even this precaution does not sensibly increase

the life of a welded joint. The object in view will certainly not be attained if, during welding, the thin ends of the studs, which project into grooves, are completely melted down, as frequently occurs with unskilled welders.

The welding process is similar to that in the welding of steel. The filler material is put down in runs; before a run of welding is put down, the surface which is being built up must be made metallically clean. In order to avoid casting stresses, welding should only be carried out at one point for such a length of time that the article near the weld zone is, at the most, so warm that one can put one's hand on it without being burnt. As soon as this temperature is



Figs. 124–127.—Preparation of electric cast-iron cold welds

exceeded the welding must be interrupted. It can be started again immediately at another point, provided this is sufficiently far away.

In spite of these drawbacks the cold welding of cast iron is extensively used because it is quicker to do and is the least expensive.

Recently, in cold welding, good results have been obtained by using Monel metal as a filler material.

The Hot Welding of Cast Iron.—As was stated at the beginning, the essential point about the hot welding of cast iron lies in the special heat treatment, before and after welding, of the casting which is to be repaired. In gas welding, preheating usually takes place in a mould, annealing furnace or refractory furnace which for welding purposes is best heated by oil, gas or electricity.

The article is welded as soon as it is heated uniformly to red heat. In this condition it is completely free from stress, since all casting

stresses which were present have been eliminated by equal expansion. In this state, the flame is unable to exercise any harmful effect, since local heating is impossible. In general, for welding purposes, the article has now to be taken out of the furnace and is therefore subjected to a cooling effect. This must never go so far as to cause the article to be endangered. In such circumstances, it is advisable to interrupt the welding process and to reheat the article in the furnace. In order to retard its cooling as much as possible and to avoid frequent interruptions in the welding process for the purpose of reheating, it is advisable, with large articles, to work with two flames, one of which is used solely for the purpose of maintaining

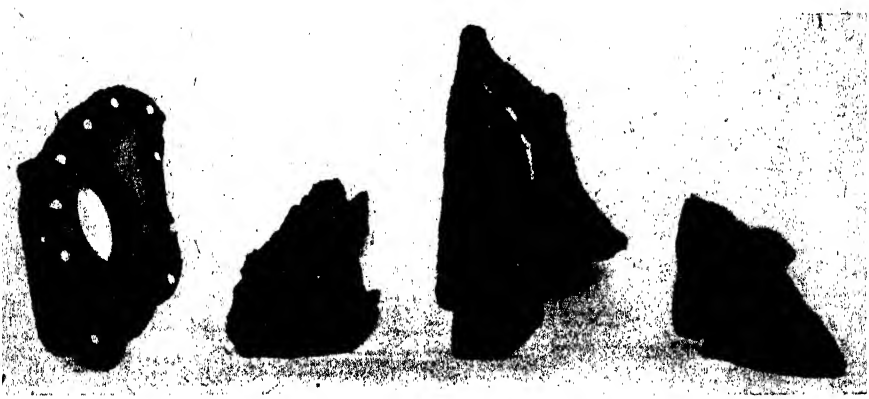


Fig. 128.—Faulty welding of a cast-iron cold weld

the temperature of the article. If the article is to be turned over it is advisable, during an interruption, to play on it with the flame.

The welding process is otherwise similar to that in cold welding.

After welding, the article must not cool down in air. This would certainly result in the introduction of new stresses and the formation of new cracks. Hence it should be allowed to cool as slowly as possible in the furnace. The slower the cooling, the more favourable is the separation of graphite and the softer will the casting become. In this way, the danger of new stresses being set up is eliminated. The quality of the weld is improved by subsequently annealing the article at red heat and this should be done directly after the welding process. This is definitely to be recommended, since in this way, all parts are once more uniformly heated and no fear need be entertained that certain parts which were more strongly heated during welding, will cause stresses to be set up on a second cooling.

Since cast iron may once more be used as a filler material, a homogeneous welding is thereby obtained. The hot welding process with the gas flame is therefore suitable for small objects of any shape as well as for large ones, and for the purposes of welding broken articles together, welding fractures, or repairing small flaws. Large faulty places in which the fractured pieces do not fit together for some reason or other, or cannot be welded together, are just as difficult to repair by this hot welding process as by the cold welding process.

The Electric Hot Welding Process.—This process differs essentially from all the previous processes which have been discussed, because of the mode of preparation. The parts of the article are not fused by butting them together or by making a weld groove, but a casting mould is built round the place to be welded, and this is filled up by molten filler material. In other words, a mould is used just as in a foundry, only this mould is built up from current conducting materials so that the arc can be struck at any point in the mould. This process, therefore, is a definite casting process.

Blocks of retort carbon (arc carbon or retort coke) are used for the mould, and these may be obtained commercially in a variety of sizes and shapes. Blocks which are provided with a tongue and groove, for example, facilitate the building up of the walls in moulds of this type. The carbon blocks may easily be shaped with a file or a grindstone, and made to any shape corresponding to the mould. With care, they may be used over and over again. They are locked together by means of bolts or wire. With large articles, in order to make the mould rigid, a plate like a moulding box, which can be fastened to the article in any way desired, is put round, and then moulding sand is pressed down behind the mould. Small shapes may be directly moulded in sand. It is then unnecessary to fit a moulding box.

Accurate instructions as to how the moulding should be carried out in individual cases cannot be given, since there is such a variety of articles and ways in which they may be damaged, that a decision can only be made in each individual case. Only after considerable experience can the most satisfactory method be adopted and good results obtained. In the following remarks, some rules relating to definite examples can be recommended, and these should always be observed.

The most important point is to prepare the weld so that one can get right down to the bottom with the welding rod without diffi-

culty. In doing this, it should be noted that the welding rod which is guided into the mould may make it possible for the arc to jump to the edges of the fracture and to the conducting walls of the mould, and hence it should not be allowed to approach them too closely, as otherwise the welding rod will stick and cause interruptions in the work. If the fracture is not wide enough, it should be widened by chipping out or preferably by drilling out before moulding in such a way that it widens out upwards. In this way the offtake of gases which are formed in the molten bath during welding, just as in casting, is facilitated. Lack of observation of these rules during preparation results not only in the formation of numerous pores and blisters, but also in the formation of channels which run vertically, and consequently make the weld porous and unfit for service.

Fig. 129.—Fractured locomotive cylinder drilled out for moulding

It should further be noted that a movement of the article during welding is impossible, since the mould contains molten iron which must solidify by slow cooling on completion of the welding process before the casting may be moved. If the fractures extend to various sides of the article, an attempt must be made to enclose them from one point with a single mould. It is usually cheaper to drill out large portions for this purpose and replace them by filler material, than to make several moulds one after another. Moreover, this is not always possible, and a second and even a third repair has to be taken into account, and this considerably delays the completion of the work, at least with large articles. An example of how repeated moulding can be avoided is shown in fig. 129. In the locomotive cylinder shown here, a crack had to be welded and a portion of the flange replaced. The crack is not welded from the side, a method which would certainly save in filler material, but from above, in such a way as to widen the crack in the way indicated. In this way, the

faulty place in the flange and the crack may be covered by one mould and welded at the same time.

If the fractured place extends for a considerable distance inwards, so that there is a fused bath of considerable area in the mould, it is impossible, even with the use of heavy currents and large electrodes, to maintain this permanently molten by means of the arc, which only acts on a small point. It is absolutely necessary for the success of the weld to maintain this bath molten. By arranging the moulding blocks in the way which is indicated in fig. 130 for a locomotive cylinder, the flange of which was broken off for a considerable width, a number of spaces is produced, of which one in every two is first filled with sand. The open spaces are now filled up in turn with filler material; then the intermediate walls and the sand in the remaining ones are carefully removed and the intermediate spaces which are formed are then welded. In this way, the worst possible damage may be repaired and faulty places of considerable size may be filled up with material. During the repair of a large pump-cylinder belonging to a hydraulic station which was carried out in the repair works of the State Railways in Wittenberge as early as 1917, about 430 lb. of filler material were melted down into the faulty place. How far one may go is entirely a question of the cost or the urgency of the repair. If the fractured parts are very bad they will, of course, not be replaced by new material, but welded together in a suitable way. In these circumstances, however, they should not be put together so that the fracture only has to be welded, but the broken pieces should be so arranged that large gaps are left. Fig. 131 shows the main bearing of a turntable which has been welded in this way. Whether the broken pieces are to be replaced or used again can of course only be decided from job to job. In by far the majority of cases, however, it will so happen that a good result can be more quickly and cheaply obtained by filling up a large faulty place with

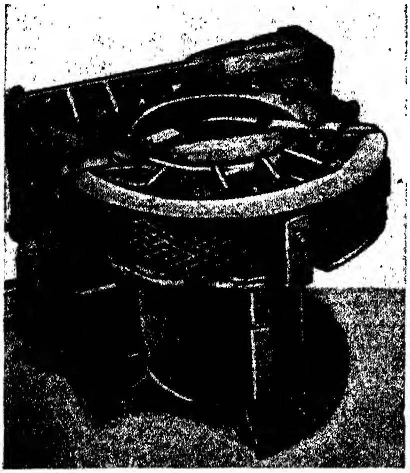


Fig. 130.—Locomotive cylinder moulded for "compartment" hot welding

new fused material, than by fitting the broken parts together again, since as a rule this results in difficult shapes and often necessitates frequent handling of the article.

Before welding, the iron is heated to red heat. For the preheating of large castings, ordinary pits are used which are built of refractory material. The mould is covered with an asbestos plate so that it cannot get dirty, and the article is surrounded by wood charcoal and heated slowly to red heat in this fire.

With large articles, the preheating process requires about a day. Smaller articles, which are simply moulded in sand, as previously mentioned, and heated with wood charcoal, require a correspondingly shorter time. Attempts made to effect a cheaper and quicker preheating by the use of cheap coke in place of wood charcoal or by building grates with forced draft firing into the pits, have proved unsatisfactory. By speeding up the preheating process, the danger of cracks occurring in cast articles, which are not entirely free from stress, is increased. In addition, with coke firing it may easily happen that the articles are melted and absorb particles of sulphur. Coke firing, as well as the use of damp wood charcoal, also requires special precautions for disposing of poisonous gases which are formed, since welding has to be carried out over the fire, while the article is at red heat. It is recommended that ventilating equipment should be fitted over the welding pits, even when wood charcoal is being used, if the welding workshop is small and not well ventilated, as it certainly should be, and if the best dry wood charcoal is not used.

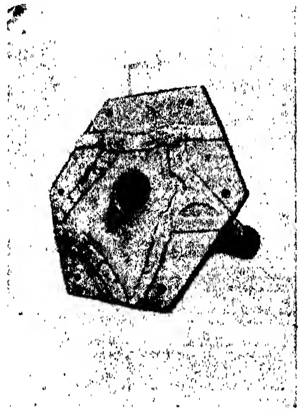


Fig. 131.—Hot-welded main bearing of a turntable

Before welding, the place to be welded should be cleaned with compressed air. In hot cast iron welding, the welding is again done according to the Slavianoff process with direct current, in which the positive hotter pole should be connected to the heavier article. Bare cast iron rods $\frac{3}{8}$ in. to $\frac{5}{8}$ in. thick, and not more than $\frac{3}{4}$ in., are used as filler material. These should be about 3 ft. long. A good chemical composition of the rod is:

Carbon	3 to 3·6 per cent.
Manganese	0·5 to 0·8 per cent.
Silicon	3 to 4 per cent.
Phosphorus	0·4 to 0·8 per cent.
Sulphur (Max)	0·1 per cent

The use of welding fluxes or covered rods is unnecessary with the hot electric welding process. In order to keep the fused bath continually molten, considerable quantities of electrical energy are necessary. Consequently it is insufficient to use an ordinary welding transformer such as may be used for cold welding. With hot welding, the welding voltage usually amounts to 40 to 65 volts (open circuit voltage 80 to 90 volts). The welding current, depending on the size of the work, and the size of electrode chosen for the purpose, amounts to 400 to 1000 amperes. Therefore, for the hot welding process, specially large converters are necessary, but several machines of the ordinary size may be connected in parallel for this purpose.

The welding itself is carried out in such a way that the arc is struck with the welding rod and the edges of the fracture are melted down at the base of the mould, after the mould has been uncovered and carefully cleaned by blowing away dirt and dust. The filler material gradually fills the mould with a fluid bath. Care should be taken that the molten iron in the fused bath does not come in contact with the fractured edges which have not yet been melted down. The fusing process must take place to the same extent as the fused bath fills up the mould.

As soon as slag collects in large quantities on the surface of the fused bath, it should be most carefully skimmed off. In order to speed up the welding process, small quantities of the same filler material, obtained from scrapped pieces of welding rods, may be added from time to time to the molten bath with a small scoop. The arc quickly melts these small pieces, but some attention may be necessary to ensure that unmelted pieces do not remain in the fused bath and become entrapped on cooling. The process in which molten iron is added to the mould in order to fill it up rapidly is not so widely used, because it is very difficult to find the correct composition of the material which ensures a good joint. Special attention should be paid to avoiding unnecessary interruptions in the welding process, so as to retain the heat in the molten bath.

The welding does not require as much skill and steadiness of hand as the cold welding process, but at the same time it requires great care. It is, however, much more fatiguing for the welder,

since the article has to lie in a charcoal fire during the welding process in order to acquire its red heat.

From the previous remarks, it will be clear that the most extensive damage to a casting may be repaired by means of the electric hot welding process, no matter whether the fractures are complicated or very extensive.

If it is skilfully done, hot cast iron welding gives a uniform joint throughout. It is usually less porous than the base material, and in consequence it usually possesses a higher strength than the former. The weld and the transition zone are soft and, in contrast to those produced by cold welding, they are just as easy to machine as the base material. Fig. 132 indicates the etched section of such a weld. Comparison with the etched figure of the cold weld in fig. 123 clearly shows the difference in quality between the two processes.

Fig. 132.—Micro-photograph of an electric cast-iron hot weld

A disadvantage of the process is that it necessitates dismantling the parts to be welded and carrying them into the welding workshop for hot welding, and that the preparation requires considerable time, and is also more costly than other processes.

The process cannot be applied to castings which have been cast so highly stressed that they cannot withstand even a slow preheating. In the same way, castings cannot be welded which have been subjected for a long time to furnace gases or hot vapours. In such cases it has been shown that decomposition and excessive ageing of the structure has taken place, and these cause the formation of large spongy spots near the weld zone which do not unite with the weld. In both these sets of circumstances, however, the other processes are inapplicable. Such castings must be scrapped.

The welding of very thin walled objects is also difficult. Here too, however, hot cast iron welding has proved suitable. A block of carbon is placed under the faulty place, and it is carefully welded with a very thin cast iron rod after the article has been heated round

the faulty place by means of a charcoal fire. Recently this process has been widely used.

In the welding of small diameter vessels the procedure is to weld with Benardo's process and carefully to warm the weld place with the carbon arc, and only to melt it down to the extent which is necessary in order to obtain a junction with the cast iron filler material.

The Welding of Cast Steel.—The welding of cast steel is similar to the welding of steel. Every process which is used for the welding of steel can be applied successfully to the welding of cast steel.

In this respect, it should be noted that articles which must not be subjected to stress are preferably welded electrically, in order to avoid the distortion which may also be counteracted by preheating. With a hard casting special attention should be paid to temperature stresses. Cavities and faulty places are best repaired by arc welding. It is advisable with large welding jobs to carry out subsequent annealing or to use the hot welding process. Large articles which stand up to excessive heat are better repaired by gas welding.

In general, the choice of the process for any individual case depends on which appears most economical. A filler material, which is as far as possible similar to the base material, should be used.

A soft wire should be used for low carbon castings and hard wire for high carbon castings. Welding fluxes are entirely unnecessary.

The Welding of Malleable Cast Iron.—Welding is difficult because of the local characteristics of malleable cast iron. In general, electric cold welding is the most suitable. The various methods of manufacture which affect the structure also render welding difficult. Light flowing cast material is best treated as cast iron, using a cast iron rod. Heavy flowing material is best treated as steel by adding mild steel wire. If malleable cast iron is to undergo shaping after welding, it must be treated with this in view. Forgeable malleable cast iron may also be welded by electric resistance welding.

The Welding of Copper and its Alloys *

Copper.—Next to steel and cast iron, copper is one of the most important metals in technical use. It is just as easily welded as the former, but possesses a range of properties which make welding

* Ziem, "The Weldability of Copper", *Technisches Zentralblatt*, Vol. 39 (1929), p. 433.

very difficult and which necessitate special precautions. These will now be discussed in greater detail.

Copper is marketed as electrolytic copper or as smelted copper in the rolled or drawn condition. The metal which is obtained electrolytically is purer. As this is too dear, however, smelted copper, which contains additional constituents to a greater or less extent, is usually used for technical purposes, and these constituents adversely affect welding if they are present in too great quantities. The greatest difficulty in this connexion is due to lead, bismuth, zinc, nickel and tin, in the order in which they are here mentioned. The presence of small quantities of lead is sufficient to make copper unsuitable for welding purposes. These additional materials should not amount altogether to more than 0·5 per cent. In addition to the metals named, copper contains arsenic. The arsenic contents which are usual do not influence the weldability of copper, however. As has been frequently suspected, working stresses render copper useless for welding purposes, if it is subjected to them for a long time.

Before welding copper, therefore, it should be tested to see whether it is suitable in respect of its chemical composition, since low quality material either gives very low strength values or leads to bad results.

It should be noted that copper is also available as cast copper, and that this obtains its fibrous structure and the high ductility, which make it so suitable for technical purposes only by means of a refining process. Copper always absorbs oxygen during casting and forms with it cupric oxide, which is deposited at the crystal boundaries and renders the metal liable to fracture. By means of rolling and drawing, the cupric oxide is made homogeneous with the crystals and rendered non-dangerous.* The strength properties of copper which are obtained in this way are once more destroyed, however, by welding, and if the weld seam and the parts which have been joined, are to have the properties of the base material, they must be restored by a treatment which is similar to the rolling process. As will be shown later, this is obtained by skilful hammering. With copper, a weld seam which has not been hammered is always unsatisfactory.

There is another difficulty during the welding of copper caused by its high heat conductivity, which is about six times as great as that of steel. Consequently, the welding of this material necessitates

* "Oxy-acetylene Tips", September, 1928.

a greater heat supply than does steel. For this reason, welding is done with a torch which should be two sizes larger than for steel, or two flames may be used. These are a distinct advantage for reasons which will be mentioned later.

It should be noted here that the melting-point of pure electrolytic copper is 1980° F. (1083° C.) while that of smelted copper is considerably lower.

The greatest difficulty in the welding of copper is due to the tendency, which increases with temperature, greedily to absorb oxygen and to form compounds with it like cupric oxide and cuprous oxide which make it liable to fracture. The only means of combating this is by making the weld most carefully. In addition copper greedily absorbs combustible gases in the molten condition, and on cooling gives them up again in the form of froth.

How these difficulties with copper are to be met and how, in spite of them, by means of the most careful *Manufacture of the Weld*, a weld joint can be obtained which satisfies all requirements, will now be discussed below. At first it should be noted that copper is almost exclusively welded with the oxy-acetylene flame. For junction welding, where material is required having the approximate strength and ductility of the base material, electric arc welding has not led to practically useful results. It has, moreover, proved to be uneconomical. Copper may be welded quite satisfactorily, however, by means of the electric resistance process and also in building-up welding by means of the arc, when only freedom from porosity, and neither strength nor ductility is required.

As far as welding with the oxy-acetylene flame is concerned, the preparation of the article, as well as the guiding of the flame, is almost entirely the same for copper as for steel. An important condition for the success of the welding is the most careful adjustment of the flame and the guiding of the torch. It is here of much greater importance than in the welding of steel. It must be carefully noted that welding is only to be done with a neutral flame. The tip of the flame cone should stay at a constant distance from the metal equal to half the length of the cone. If the torch works with excess oxygen, there is the danger, as has already been mentioned, that oxygen will pass into the copper. Not only does it form cupric oxide on the surface and overheats and burns the copper, but it also passes into the molten copper during welding to form cuprous oxide. In addition, the combustible gas which is present in the flame is, as stated, gradually absorbed by the molten copper, and this is set free

on solidification of the copper and rises spontaneously to the surface in the form of small blisters. This is called " copper froth " and also " copper spit ". If solidification takes place quickly the blisters will be trapped and cause a porous spongy weld.

Burned copper, which may be distinguished from the salmon red of pure copper by its dark red colouring, is brittle. Even the presence of ·1 per cent of cuprous oxide considerably increases the tendency of the material to fracture. Since the formation of cuprous oxide cannot be avoided, even with the most careful adjustment of the flame, it is advisable, by the addition of deoxidizing agents as additional materials in the fused bath, once more to reduce the oxide which is formed. Such agents are magnesium, aluminium, silicon, phosphorus, iron and especially silver. Phosphorus has shown itself very suitable for the deoxidation of copper. It combines with the cuprous oxide to form phosphoric acid, which because of its low specific weight rises to the surface of the molten mass and vaporizes. For quality welding the Canzler wire which is made in Germany has shown itself very suitable. This contains about 1 per cent of silver in addition to phosphorus. The filler material should only contain as much phosphorus as is absolutely necessary for the reduction of the cuprous oxide. An excess quantity passes into the copper and makes it brittle. Electrolytic copper is not to be recommended for use as a filler material. Although this is very pure it should be noted that experience has shown the weld to be very much better the more exactly the filler material is suited to the base material, if copper of about 99·5 per cent purity is available. In electrolytic copper there is a lack of the protective elements which prevent the absorption of oxygen. In addition it has a higher melting-point than smelted copper, and this also makes welding more difficult. Experiments have shown that seams welded with electrolytic copper have a very low ductility.

In order to combat the effect of oxygen as much as possible, it is necessary, besides adjusting the flame accurately, to speed up the welding process as much as possible and to shield the weld zone with the flame, so that oxygen from the air cannot enter. For this reason, a more powerful torch must be used than for steel as was mentioned in the previous pages. This is also necessary in order to retain the quantity of heat which is necessary for the welding process at the weld in spite of its being conducted away because of the high conductivity of copper. Working with two torches, one of which is used for the welding itself and the second which is used

for keeping the heat at the weld zone and shielding it, has proved very satisfactory. With heavy sections, provided that the weld is accessible, one may weld simultaneously on both sides after making an X-shaped groove, so as to employ the torches most usefully. In this way the danger of insufficient fusion at the root of the groove need not be feared. It only arises if the two weld grooves are filled up one after the other.

It may be noticed in these instructions that the use of a welding flux, which is usually referred to as being indispensable for copper welding, is not absolutely necessary. Nevertheless, it is advisable to use a welding flux on heavy sections. Since, with heavy sections, the neighbouring parts of the seam are strongly heated, and since these may become brittle by the absorption of oxygen from the air, they should be protected by a welding flux, which covers them with a non-porous easy flowing skin. At the same time inclusions should not remain behind in the weld. Welding fluxes consist chiefly of borax. The melting-point of the flux must lie below that of the copper.

The use of a more powerful torch and the increased speed of the work which is thereby obtained, is also necessary because with it the heating of the parts of the article which adjoin the weld seam may be limited to a minimum. With increased heating the whole material expands considerably because of its high heat conductivity and hence on cooling, dangerous stresses which are called into play after a long period of welding at high temperatures, are set up and lead to shrinkage cracks such as frequently occur in copper welding. The quicker the welding takes place the lower may the stresses be kept. These stresses, which can never be completely avoided, may also be neutralized by *Hammering the Weld Seam.* As was mentioned, this hammering is indispensable for converting the cast structure which is set up by the welding into a fibrous one, and for giving the weld seam the strength properties of the base material. The strength of an unhammered weld, even with the use of alloy welding rods, amounts at the most from 50 per cent to 60 per cent of the unwelded plate and this is, therefore, too low. The hardness of unworked welds is also considerably lower, as these are coarse grained and invariably more or less porous. Hammering, therefore, always forms an essential part of the welding work.

This hammering must be carried out with considerable skill. It requires special dexterity, and should result in the consolidation of the weld and in the improvement of the crystal structure.

In order to avoid the difficulty which is introduced by hammering the weld seam at high temperatures because of its low strength, the work should be carried out directly in conjunction with the welding. A piece is welded and immediately hammered. The first portion of the piece must, however, be still at red heat when the hammering is started, otherwise further heating with the torch must take place. On account of the stresses which are set up, going over the unworked seam with the weld flame again is to be avoided as far as possible. In general, about 6 in. are welded and then hammered.

The end of the weld seam is then hammered over quite lightly in order to consolidate it to some extent, and then a return is made to the starting-point of the welding. Because of the softness of the material, the seam would fracture at its end point, due to the stretching which is set up by hammering, unless this precaution were taken. The intermediate zone between the weld seam and the plate is then worked, and in this way a smooth and uniform transition can very easily be achieved. It is advisable to weld with a small reinforcement so as to be able to build up the material. After the two edges of the weld seam have been hammered over, the reinforcement itself and the weld seam which is integral with it, is carefully worked along its whole length. If hammering of the weld seam is started in the middle, a large portion of the reinforcement is forced out to the sides, and it is impossible to get a uniform transition zone in the plate. When the hammering is started, the blows must only be light as the weld is at a high temperature. As the cooling increases, and especially after the first hammering of the weld seam, the blows should increase in intensity, so that a change in the cast structure does actually take place at all points in the section of the seam. With longitudinal seams, it is advisable to have the hammering of the weld directly followed up by a second workman.

In the welding of fire boxes, a hammer weighing about 2½ lb. or a compressed air hammer is used. Heavy hammers cause the structure to break up and they should, therefore, not be used. When welding from both sides, the blows from both sides should be made simultaneously.

Finally the hammered seam may be smoothed over with a compressed air hammer, and this is especially advisable for articles which have projecting members, which may be subjected to serious attack from gases, &c.

In addition to this improvement by hammering, it is advisable in special cases, to carry out subsequent treatment by annealing and

slow cooling at a temperature of about 750° F. (400° C.) for half to about one hour, and in this way a very regular structure may be obtained. By observing these instructions it is easily possible for a skilled welder to produce satisfactory welds having a strength up to 90 per cent of the unwelded material. It is always advisable, however, to test the skill of the welder by test welds, and bend tests, and an angle of bend of 180° should certainly be specified.

*Brass.**—Brass is a copper zinc alloy which, on welding, behaves like copper so that the same precautions are to be taken with it. It should be noted, in addition, that brass has a property which renders welding more difficult, and this is the low melting-point of zinc. It lies at about 785° F. (419° C.), i.e. under the melting-point of brass, 1710° F. (930° C.), and well under that of copper, 1980° F. (1083° C.). Consequently, on welding, zinc easily vaporizes, and this gives rise to porous and spongy welds.

For this reason, welding should be speeded up as much as possible. The loss in zinc does not increase with the heating of the molten bath, but with the time of welding. By rapid fusion, therefore, the zinc loss may be kept small. The welding of thick members is very unsatisfactory as they require considerable time for heating.

As copper-zinc alloys oxidize easily, a good welding flux is to be recommended. A mixture of borax or boric acid with sodium phosphate is frequently used. It may be put on the metal in the powdered condition or as a paste. The welding rod is also dipped into the flux in order to protect it from oxidation. In spite of the easy oxidation of the metal, however, slight oxygen excess in the flame is not so dangerous as with copper, since the oxygen forms a protective skin of oxide over the molten bath.

The flame cone should be held a little farther away than with copper. If this is brought too close to the metal it causes the molten bath to froth, and this vaporizes the zinc more quickly and the weld becomes porous. It is advisable with heavy material thicknesses to use several torches and, by uniform heating, to avoid local overheating of the article.

The filler material must exactly suit the base material. It should be noted that the properties of the former do not depend alone on its chemical composition, but also on its heat treatment and its cold treatment. The welding wire should, therefore, be alloyed.

In spite of this, it is practically impossible to give a brass weld

* Canzler and Holler, "The Weldability of Brass and Bronze", *Technisches Zentralblatt*, Vol. 39 (1929), p. 438.

the same shade of colour as the base material. Consequently, assistance is frequently sought from brazing, in which the difficulties do not arise to the same extent as in welding.

Hammering the weld should only be carried out with rolled brass in the cold condition and with cast brass in the hot condition. Quenching brass makes the metal brittle.

Bronze and Red Brass.—These are copper tin alloys. The same precautions are to be observed with them as with the copper zinc alloys. A difficulty is introduced, since, in the heated condition, bronze loses virtually all its strength and even slight shocks may lead to a fracture of the article. In the heating of a large article its own weight may even act in this way. During welding, therefore, the work must be well supported and not moved about.

The choice of a filler material is even more difficult than with brass since the difference in the alloys used for various bronzes are greater and voltage potentials may easily be set up between the welding and the material.

Building-up welding with red brass, using the electric arc, has proved satisfactory. It is welded with the carbon arc with a voltage of 45 to 65 volts, and with heavy equipment such as is used in cast iron hot welding.

In addition, the point which will be specially raised later during the discussion of accident prevention is made here: that, due to harmful tin or zinc vapours which are developed during the welding of copper alloys, the provision of gas masks (respirators) must be officially specified for the welder.

The Welding of Aluminium and its Alloys *

Aluminium is also a metal which is of considerable importance in welding engineering, since it is entering into technical practice more and more. This is due to the low weight which it possesses in spite of its relatively high strength and also to its resistance to chemical action. For this it is indebted to an extraordinarily thin coating of

* Pothmann, "Concerning the Welding of Aluminium and Light Alloys", *Autogenschweisser*, 1928.

Holler, "Principal Points in the Aluminium Welding Processes and their Technical Significance", *Autogène Metallbearbeitung*, Vol. 21 (1928), p. 46.

Rostosky, "The Soldering and Welding of Aluminium", *Metallkunde*, Vol. 15 (1923), p. 196.

Rostosky, "The Soldering and Welding of Light Metals", *Metallwirtschaft*, Vol. 9, (1930), p. 499.

Holler, "Aluminium and its Weldability", *Technisches Zentralblatt*, Vol. 39, (1929), p. 47.

oxide with which it covers itself even in air on account of its great affinity for absorbing oxygen. At the same time this aluminium oxide has a very high melting-point which lies between 3600° and 4500° F. (2000° and 2500° C.), whereas the melting-point of pure aluminium only amounts to 1200° F. (650° C.). This property, which is so valuable for the chemical industry, provides the greatest difficulty for welding. The fusing of this oxide skin with the flame cannot be carried out for reasons which are easy to explain. Consequently the welding of aluminium and also the associated hard soldering process, was first made possible when a flux was found which caused the chemical decomposition of the thin oxide skin. The flux, which is termed "*Autogal*" is protected by patents. It consists primarily of alkali chlorides and fluorine compounds.

Since this flux is very deliquescent and then loses its ability to dissolve oxygen, it must be kept protected from the air and only used in such small quantities as are necessary to carry out the work, by mixing it in a small dish. For thin plates, it is used either with water or alcohol, mixed in the form of a pasty mass which is put on the weld with a small brush. For heavy sections the powder is scattered in the finely divided condition over the weld, and the welding rod is dipped from time to time in the powder. There is no point in sparing the flux since it has the effect of making the metal lightly flowing, and it favourably affects the fusion process. The remnants of the flux should not remain in the weld, and this makes careful work imperative. After welding, it is also very important to remove all traces from the weld by washing with water, otherwise corrosion of the aluminium is set up by the flux which remains behind. Pure aluminium is used as a filler material either as a rod or scrap from aluminium plate.

As far as fusion welding is concerned, as was the case with copper, gas welding is practically the only process used. For thin plates, a light flame is more suitable, as with a strong flame holes may easily be burned through. For this reason oxy-hydrogen or illuminating gas and compressed air flames are very often used. For heavier sections, however, it is better to choose the oxy-acetylene flame because acetylene results in softer welds. It is necessary, however, to subject it to a very careful purification from sulphur and phosphorus compounds, so that the weld does not lose its strength.

Thin plates are prepared by folding or flanging, and these may be welded without filler material. Heavy sections are butt welded together. As a rule the making of a groove is unnecessary.

Metallic cleaning of the surface should not be omitted.

The *Welding* itself, therefore, requires considerable practice and experience on the part of the welder, since the change from the solid to the liquid state occurs very suddenly with aluminium without its giving any definite indication. The danger of burning holes is, therefore, very great, especially with thin plates. On the other hand, because of the conductivity of aluminium, which is about half that of copper, a relatively long time elapses before the fusion process commences, so that the welder is easily led into using a heavier torch than is prescribed. Therefore, as soon as the preheating of the weld becomes excessive, the fusion process takes place more quickly than the welder is able to follow up with the addition of filler material, and hence overheating results. Care is therefore required. If the weld bead is too wide, it is an indication that the welder should take care. He must then take a smaller torch. Dimensions which are frequently given, for example, that the width of the bead should be three times the thickness of the plate, would naturally result in welding beads which would be very much too wide for heavy thicknesses. Preheating of the article is to be recommended in order to render possible an earlier start in the welding process, when the work is first begun. A slight stirring with the welding rod in the molten bath in order to assist the separation of slag should not be forgotten.

Since aluminium also collapses very easily at the welding heat, it should not be forgotten that the welded article should be well supported. Pieces of steel plate put underneath may easily be removed after welding since aluminium does not adhere to steel. By means of a subsequent treatment such as annealing and hammering, the strength properties of the weld may be increased. Quenching contributes to an improvement in the fused structure, but may result in shrinkage cracks. The pressure welding process is also used with aluminium—so-called forge welding—and this will be discussed in greater detail in Chap. III. Attempts have been made to weld aluminium plate by the electrical spot welding process, but up to the present time with little success. Attempts have also been made to weld aluminium by means of electrolysis. Up to the present they have had no practical importance. On the other hand, welding with the electric arc, which has recently been taken up, is deserving of more attention.

For this process new electrodes have been developed which are covered with an oxide dissolving paste. They are melted down with

the normal welding equipment. The electrodes are connected to the positive pole. A glass-like layer of slag, which forms easily on the surface, protects the molten aluminium from oxidation. It is advisable to preheat the article at the point where the weld seam is started before the work is begun, to 200 to 300° F. (100 to 150° C.) in order to speed up the starting of the welding process, which otherwise takes too long. When the seam is finished, it must be well washed and brushed in order to remove any remaining traces of the paste.

It should be granted that, with arc welding, due to the concentrated heat of the arc and the momentary formation of a fused bath, a sound joint may be made with the base material, and, in addition, that the quantity of the filler material melted down in unit time is greater than that with all other processes. There are, therefore, advantages both in strength and in cheapness. On the other hand, tensile stresses are set up in the article due to the greater heat of the arc. The process is, therefore, less suitable for the manufacture of complicated articles than for the joining of flat plates.

As far as *Aluminium Alloys* are concerned, one distinguishes between cast alloys and forgeable alloys.

The most important cast alloys are the so-called American alloys of aluminium and copper, the German alloys of aluminium, copper, zinc and Silumin, an aluminium silicon alloy. The most important forgeable alloys are duralumin, which contains the alloying constituents of copper, manganese and magnesium, and is extensively used because of its valuable properties, especially its strength which is about 31·7 tons/in.^{2}, and in addition Aladur, Lautal and recently Telectal, Aldrey, Montegal and Constructal.

All aluminium alloys may themselves be welded just like the pure metal. In these circumstances, however, it is necessary that the composition of the filler material corresponds as accurately as possible to that of the base material. The forgeable alloys, however, lose their valuable properties, which are obtained by the process of manufacture by refining, and this occurs at a temperature of 660° F. (350° C.). They then have no better properties than pure aluminium. Since the use of this alloy depends on its refining, up to the present time riveting has been retained. At the same time, the strength which has been lost in the welding process may be restored to a certain extent by subsequent treatment which is similar to the heat treatment employed during the manufacture of the alloy. In this way with aluminium, strengths up to 25·5 tons/in.^{2} have been

obtained. For this purpose, however, the welded article must be heated in a furnace to 900° F. (480° C.), and then quenched in cold water or oil, and this is usually impossible to carry out in practice with large articles. It has been reported that the Metallurgical Laboratories at Philadelphia have constructed an automatic electric furnace in which complete wings and rudders of aeroplanes may be treated in this way.

On the other hand, cast aluminium alloys do not give rise to any difficulties other than those met in the welding of aluminium. In common with it, they have the property that they form a ductile oxide skin on the weld and the molten metal. In general, therefore, it is necessary to employ the flux Autogal, but at the same time Silumin, which is easily welded, may be worked in small plate thicknesses without the flux. From another point of view also, the aluminium-silicon alloy is more easily welded than the aluminium-copper or aluminium-zinc alloy. Alloys react very differently to heat stresses such as occur during welding and which lead to the formation of cracks. The better weldability of Silumin compared with both the other alloys is due to its crystalline structure and its solidification curve.* The internal stresses which remain in welding may be removed by subsequent annealing of the article. Heating in a wood charcoal fire at a moderate temperature and slow cooling is even more to be recommended.

The Welding of Nickel and its Alloys †

Nickel may be welded by means of the electric resistance welding process, by butt or spot welding as well as by the fusion welding process using the electric arc or the oxy-acetylene flame.

With reference to the welding process, it has been shown in practice that, with plate thicknesses greater than $\frac{1}{16}$ in. metallic arc welding gives better results, whereas with thin material the oxy-acetylene welding process may be employed with better success.

With both welding processes, it should be borne in mind that nickel has the property to an even greater extent than copper, although in other respects it behaves the same, of absorbing gases in the molten condition and consequently special precautions are to

* Scheuer, " The Weldability of Aluminium Alloys depending on the Type of Alloy ", *Schmelzschweissung*, Vol. 9 (1930), p. 178.

† Woehlers, " Concerning the Welding of Nickel ", *Technisches Zentralblatt* (1929), p. 447.
Boutte, *Revue de La Soudure Autogene*, Vol. 21 (1929), p. 1710.

be used with it in order to obtain a satisfactory weld without pores and blisters. Due to ignorance of these facts, the welding of nickel has, up to the present, only been carried out to a limited extent.

It should be added that nickel contains many impurities such as carbon, sulphur, iron, cobalt, manganese and silicon, and of these sulphur is most harmful during welding and reduces the strength. By means of a suitable welding flux the sulphur must so be combined in the nickel that it is insoluble.

In arc welding, a pure nickel electrode is employed with a deoxidizing covering which consists chiefly of ferro titanium. Direct current is definitely to be preferred to alternating current.

The welding should be carried out in one run over the whole section. Building up in layers leads to bad welds because the skins of oxide which are formed on the layers are entrapped in the weld.

In oxy-acetylene welding a neutral flame is imperative, and better still a slightly reducing one. Excess oxygen makes the weld brittle. It is advisable to use the backward welding process since in this case the flame shields the seam which has already been welded, and prevents the absorption of oxygen from the air. A rapid to-and-fro movement over the surface is advisable in order to anneal the seam and hence to remove stresses. In no circumstances is the welding process to be interrupted, but at the same time building up the weld in layers is to be avoided. Finally, it is important that the torch should be held at an angle of about 45° to the seam.

German Silver.—Since German Silver is a copper-zinc alloy of nickel, what has already been said about brass also applies to this. The welding process must be carried out as quickly as possible in order to keep the vaporization of the zinc within moderate limits. Oxidation is prevented by the addition of aluminium or magnesium. Annealing and hammering at about 1300° F. (700° C.) is necessary.

*Monel Metal.**—This alloy of nickel may be welded either with the electric arc or with the oxy-acetylene flame. In both cases, it should be noted that Monel metal easily absorbs carbon and oxygen and becomes brittle.

In arc welding, therefore, a covered electrode made of monel metal must always be used or welding must be carried out under a protective shield in order to keep the air away. Alloys of magnesium, manganese and silicon, or titanium and calcium, are recommended as coverings.

* Neese, " The Welding of Monel ", *Technisches Zentralblatt*, Vol. 39 (1929), p. 445.

In gas welding, as with nickel, backward welding gives a better weld than forward welding because it protects the finished weld from the absorption of oxygen from the air. In no circumstances should the flame have excess oxygen. On the other hand, a slight gas excess is not dangerous. Consequently the source of acetylene must supply an adequate quantity of gas. For deoxidizing purposes a flux, consisting of a solution of boric acid in alcohol, is advisable, and through this the acetylene gas is led. The addition of the flux is in this way rendered more uniform than by using a powder or a paste.

The Welding of other Metals and Alloys

Lead.—Fusion welding of lead is nothing more than the long-known lead-burning. A thin layer of lead oxide forms very easily on the surface. The melting-point of the oxide is higher than that of the lead, and this makes the welding work difficult. The scraping off of this coating before welding and a brisk movement of the welding rod in the molten bath while the work is being done are indispensable. The hydrogen flame is to be preferred. Lead vapours are extraordinarily poisonous.

*Zinc.**—The welding of zinc with the addition of pure zinc and the use of an ordinary soldering liquid flux or sal-ammoniac solution has not led to good results. Good results may be obtained with a welding flux made to an American patent, or better still, with hollow welding rods filled with a flux which is protected by patent by the firm of Griesheim-Elektron.

Tin.—The fusion welding of tin is the same as the well-known soldering process.

Elektron.†—There are weldable and non-weldable alloys of elektron. Since magnesium, which is the main constituent of elektron, is more sensitive than aluminium to chemicals and atmospheric affects, the removal of the oxide skin and the flux which is used for this purpose is more important than for the aforementioned metal. Fluxes which contain chlorides seriously attack magnesium. They must, therefore, be avoided. An alloy of the base metal is used as a filler material. The method of welding is the same as with aluminium.

* Lehmann, "The Gas Welding of Zinc", *Schweisstechnische Rundschau des Technisches Zentralblatt*, Vol. 2 (1930), p. 211.

† Rostosky, "The Soldering and Welding of Light Metals", *Metallwirtschaft* (1930), p. 499.
Horn, "Incursions into Welding", *Schmelzschweissung*, Vol. 9 (1930), p. 135.

3. The Soldering and Brazing of Metals.*

Soldering is a process which is very closely associated with fusion welding, and it approximates very closely to it in lead burning and the hard soldering of aluminium, so much so that the line of demarcation between them may scarcely be recognized. The *Definition* of the Lötausschuss (The Soldering Committee) of the Deutsche Gesselschaft für Metallkunde (German Association for the Science of Metals) is as follows: "Soldering or brazing is the joining or building up of heated metals and alloys, which stay in the solid state, by means of a molten metallic junction medium."

Whereas in fusion welding heating must proceed so far that the base material and the filler material, which should have as similar a composition as possible, pass into the molten condition and fuse with one another, in soldering it is sufficient to heat them to the melting-point of the solder, which is lower than that of the work, so that the latter remains in the solid state.

In this way, the joint between the solder and the article is not obtained solely by tacking them together, as is assumed, but the solder forces its way to a greater or less extent into the base material so that a mixture of the metals occurs, even if it is only a surface one, and this is obtained by a displacement of the surface molecules in the heated article. Even in the best case, however, the joint only attains the strength of the solder. Diffusion, viscosity and surface stresses determine the quality of the joint. The nearer the melting-point of the solder is to that of the base material and the thinner the layer of solder, the better the joint.

In soldering we distinguish between Soft Soldering and Hard Soldering.

In *Soft Soldering*, the parts which have to be joined are not heated, and a very easily fused metal (soft solder or tin) is melted with a soldering iron in a thin layer on to the cleaned metal of the parts to be joined, which have been pickled beforehand with an etching medium. The soldering iron is heated in a coal fire or by a combustible gas or by means of an electric current. If the article is large a soldering lamp or soldering pistol is used.

*The German word "Löten" may be translated in English as "soldering", "brazing", and frequently as "bronze welding". There is considerable confusion in English technical literature as to the exact meaning of these words, and they are used differently by different writers. The reader must interpret the use of these words in accordance with his own terminology, although the most usual equivalents have been used in this translation.

In *Hard Soldering* the parts of the article are preheated in a wood charcoal fire, or better still, and more cleanly, by means of the gas flame of a torch or in a furnace. Then the filler material, the hard solder is melted in. Acetylene, hydrogen, illuminating gas, Blau gas and benzine are used as combustible gases with oxygen, and, in addition, mixtures of illuminating gas and compressed air, and acetylene and compressed air, are used. These gases give a flame which is not so hot, and consequently have the advantage that the soldering process may be better observed with the naked eye than through the dark glasses which have to be used to protect the eyes when a point flame is employed.

In hard soldering, too, it is of extreme importance that the surface of the metal parts which have to be joined should be metallically clean. Fat, oil and metallic oxides otherwise lodge between the solder and the metal, or they vaporize during the welding process and prevent the joint from being made.

Soldering requires experience and skill. One must primarily be able to judge when the solder has the correct degree of fluidity, and then the soldering must be carried out quickly. The more quickly it is carried out, the thinner will be the layer of solder which is deposited between the two metals.

Copper may be soldered to copper, brass to copper, iron to copper, iron to brass, and also steel to steel. A hard solder, consisting of about sixty parts of copper and the remainder of zinc, is used as a filler material.

Soldering has acquired considerable importance in engineering work for aluminium and its alloys.* It will, therefore, be discussed in greater detail.

Soft Soldering, as well as hard soldering, is used for *Aluminium.* Just as was the case in welding, it is a preliminary necessity for the oxide skin, which is difficult to fuse, to be broken down before the work is carried out. In soft soldering, this is done mechanically. The portion to be soldered is heated until the solder which is applied melts, and this is then rubbed off with a wire brush. In this way the skin of oxide is, as it were, stripped off in the liquid solder. Hence the solder covers the portion which is to be soldered and prevents the oxide skin from forming again. Soft solders which are free from aluminium, or contain only a trace of aluminium, are used as

* Rostosky, "The Soldering and Welding of Light Metals", *Metallwirtschaft*, Vol. 9 (1930), p. 499.
Rostosky and Lüder, "The Capacity of Aluminium for Soldering with Special Reference to Hard Solders" *Technisches Zentralblatt*, Vol. 39 (1929), p. 450.

solders. They have the drawback that they provide a soldered zone of very low strength, and this is reduced in the course of time and finally disappears altogether, as soldered places disintegrate in time in the presence of oxygen and moisture, that is, in the presence of air, because of electrolytic processes. In addition, their colour grows darker and this, as a rule, is undesirable.

In spite of the advantages of the soft soldering of aluminium, which are due to the fact that no practice is necessary, no flux needs to be used, and the work may be carried out at a relatively low temperature, so that, with castings, stresses and cracks may be avoided, the use of soft aluminium solder is only advisable where there is no question of strength or where the soldered places are protected by oil, paint or lacquer against the influence of oxygen. When soft solders, which are free from corrosion, are offered for sale, it only means that the purchaser will certainly be disappointed.

Hard soldering is very similar to welding; the higher the aluminium content of the solder and the higher the melting-point, the greater the similarity.

Hard aluminium solder, also called " Refined solder ", consists of from 70 to 75 per cent of aluminium. The remainder consists of copper, nickel, silver, manganese, zinc, cadmium, silicon, cerium, titanium, &c. The working temperatures lie between 1000–1165° F. (540°–630° C.), so that in certain circumstances they approach very closely to those of aluminium welding. Going to lower fusion temperatures, however, would result in an effect which would be detrimental to the corrosion resistance, which is the special property of hard aluminium soldering as compared with soft aluminium soldering. As in welding, fluxes are used for destroying the oxide skin, and these fluxes consist of alkaline halogens, alkali earths, and metallic earths, and are not covered by the Griesheim patents. With hard aluminium soldering, the colour of the soldered places is retained.

As far as aluminium is concerned, hard soldering and welding supplement one another very well. Hard soldering has an advantage, especially for lap joints and thin plates, because of its lower working temperature. It is simpler because holes are not so easily burned in, and the seams have a cleaner finish. In many respects soldering is also more advantageous than welding for alloys. However, the same remarks apply to the forgeable alloys such as Duralumin, Lautal, Aludur, as applied for welding. At the soldering heat they also lose their valuable properties. Since the strength, however, is always

about twice as great as that of annealed pure aluminium, and since softening is confined to the joint, there is, in general, no objection to the hard soldering of heat treated alloys.

In conclusion, the brazing of cast iron must be mentioned. A large number of brazing media for cast iron is always being offered for which it is claimed that they are suitable for the making of brazed joints which equal the strength of the article and even exceed it. Thorough tests of these brazing media by the Welding Research Department of the State Railways at Wittenberge have proved the complete unsuitability of most of them.

It is only recently that, by bearing closely in mind the properties of cast iron, success has been achieved in the production of suitable brazed joints by the use of a special bronze or special brass. These joints are wrongly referred to as bronze welds. As was mentioned in the discussion on cast iron welding processes, the carbon is separated in the form of graphite in cast iron through which it runs in the shape of long drawn out veins. The success of brazing is due to the fact that this separated graphite in the cast iron is burned out at the brazing zone, so that the brazing material, which is melted down by the welding torch, is drawn into these hollow places by the effect of capillarity, and in this way forms a union with the cast iron parts, so that the strength of the joint is increased in the way desired. In order to assist this process, a paste of iron turnings and boric acid is employed, and this is put on to the edges of the article. If the article is heated the paste gives off oxygen, which oxidizes the carbon to CO_2.

By this method, the brazed places acquire adequate strength, and they are soft and may be stressed. The strength may be increased by suitable treatment by heating to a temperature of 1300–1480° F. (700–800° C.) The formation of mixed crystals of cast iron and the copper zinc alloy may be obtained, and this results in an increase of the strength properties. If the work is successfully done, brazing is therefore to be preferred in many cases to cold welding.

A completely new brazing process for cast iron using cast iron rods and a brazing solution, in addition to a paste, has led to the same results as in high class brazing using bronze.

A limitation must, however, be pointed out, namely, that success in cast iron brazing cannot be obtained at the normal brazing temperatures, since at these temperatures pores and blisters are usually formed. One has to bring the working temperature up to almost

welding temperature in order to obtain serviceable brazed joints. There is always the advantage, however, which brazing has compared with hot welding, and that is that the parts, which have to be repaired, do not need to be dismantled, and a mould built round them.

Moreover, since the quality which may be achieved is frequently governed by incidental factors, brazing for cast iron is in many cases to be preferred to cold welding if the work is done successfully, but it never reaches the quality of hot welding.

An exception is provided in the brazing of very old cast iron. As was pointed out during the discussion on welding processes, this is absolutely unweldable or may only be done with great difficulty. In brazing, the brazing material can flow quite well into very large veins and branches in the base material and form an intimate junction with it. At the same time, the decay of the base metal is not rectified unless it comes in contact with the brazing material. Nevertheless the brazing of very old cast iron affords the only means of realizing, to some extent, a serviceable repair on the article.

CHAPTER III

Pressure Welding

Forge Welding

Among the various pressure welding processes, forge welding should be mentioned first. In this process the articles to be welded are heated in a smith's fire or by water gas, while the welding process is carried out by forcing or pressing the members together with a hand hammer, a steam or air hammer, or by the hydraulic press. As fire welding, it is the oldest of all processes, and has been carried out for centuries. Although it has been forced into the background by modern methods, since it has various drawbacks, such as absorption of sulphur from the coke, inclusions of hammer scale, &c., it is used even to-day in all smithies, especially for odd articles. The process is known to every metal worker and engineer, so that there is no need to discuss it further.

The process of forge welding is not only used for steel but also for *Aluminium*. Copper may also be welded in the fire, but this is difficult because the absorption of oxygen can scarcely be avoided. The welding of aluminium is essentially similar to the welding of steel, but the peculiarities of aluminium necessitate special precautions.*

As in the fusion welding of aluminium, the thin oxide skin on the surface of the metal, which prevents the making of a joint, must be removed before welding. This is done with the help of a scraper with which the overlapped parts are made metallically clean. Then the edges of the plate, which are to be hammered together during the welding process, should be scraped down to a gradual taper, since, if the edges are sharp, an early disintegration of the joint is to be feared. The welding process takes place at a

* Holler, "Important Facts relating to Aluminium Welding Processes and their Technical Importance", *Autogene Metallbearbeitung*, Vol. 21 (1928), p. 66.
Holler, "Dangers in Aluminium Forge Welding", *Autogene Metallbearbeitung*, Vol. 21 (1928), p. 113.

temperature of about 790° F. (420° C.). To hit on the correct moment is difficult, since the metal does not change colour during heating. Consequently pastes which become black over a temperature range of round about 790° F. (420° C.) or copying ink pencil lines which go white, are used as auxiliary means. Since the anvil conducts too much heat away, it is advisable to provide welding backing pieces which can be kept at a temperature of 570° F. (300° C.) by an auxiliary flame. Dust, rust and grease should be carefully kept away since they hinder the making of a joint.

The forge welding of aluminium, therefore, requires considerable experience and skill, and hence its use can only be recommended where a skilled personnel is available.

As a second kind of forge welding, *Water Gas Welding* was introduced towards the end of the previous century for the manufacture of large pipes, containers and boilers. Because of the expensive plant which is necessary, it is limited to a few firms which carry it out with considerable success. Since it is essentially a machine welding process, greater trust is placed in it than in fusion welding, especially in boiler fabrication.

In water gas welding, the heating of the plate edges, which are to be welded, is carried out by means of the water gas flame. Water gas is produced in a cylindrical furnace which is filled with red hot coal, and into this furnace air and steam are blown alternately. By blowing in the air, the coal is first brought up to white heat (hot blow). The gas which is produced in this way is sent to waste since it is of small value. In the following blow with steam (cold blow), the coal is decomposed into hydrogen and oxygen. Oxygen forms carbon monoxide with the carbon. The production of water gas, which consists of about 50 per cent Hydrogen (H_2), 39 per cent Carbon Monoxide (CO), 6 per cent Nitrogen (N_2), and 1 per cent Methane (CH_4), is interrupted after about 5 to 7 minutes and air is blown through for heating the coal.

The calorific value of water gas amounts to about 225 B.Th.U.s per c. ft. (2000 kg. cal. per cubic metre). The gas is very suitable as a source of heat since it has a reducing effect, that is, it prevents the formation of oxides on the surface.

Water gas is usually supplied to two burners which are arranged like a pair of pliers on both sides of the plate which is to be heated. In these burners it is mixed with air at high pressure and this draws in the water gas. The mixture of gas and air burns on exit from the nozzle slit of the torch in the shape of a point flame at about 3300° F.

(1800° C.). The plates which have been heated to welding heat are then welded under the hammer or under pressure rollers which, on large jobs such as boiler welding, are worked mechanically. The movement of the articles is also obtained by mechanically operated carriages or welding streets.

Electric Resistance Welding *

One pressure welding process, which was used by C. Thomsen for the first time in 1887, is the electric resistance welding process. It is based on the fact that when an electric current flows through a light conductor the latter is strongly heated and the articles which have to be joined are brought to the welding heat in a very short time. Suitable machines are constructed which, after the welding heat has been attained, carry out the pressing together of the articles to be welded. In this process, the electrical energy is primarily converted into heat because of the transfer resistances between the articles to be welded at the point of contact and also to a slight extent because of the internal resistances. Since it is possible to conduct the current through the article in such a way that heating is only set up at the point where it is required during the welding process, electric resistance welding is considerably superior to forge welding, from the economic and the thermal point of view. A further advantage in electric welding is that the welding process may easily be watched, so that the work may be delegated to unskilled workmen, and, moreover, practically no rejects occur due to overheating of the material. In addition, the electric welding machine is ready for service at any time; no waiting periods are required, and it takes up relatively little room, and does not spoil the air with carbon monoxide gas as does the smith's fire. With this process the old unhealthy, dirty smith work is replaced by a clean process.

Upset welding, spot welding and seam welding belong to the electric resistance welding processes. A fourth process which will be included here and which has been developed from the above is the flash welding process. It is, however, wrong to treat it as a division of the upset welding process, as it is a process in itself and is based on entirely different thermal processes. The heating of the butting surfaces is not only achieved by means of internal resistance

* Goldmann, "The Present Position and the Further Development of Electric Resistance Welding", *Technisches Zentralblatt*, Vol. 40 (1930), p. 150.
Schröder, "The Electric Resistance Welding of Various Metals," *Technisches Zentralblatt*, Vol. 39 (1929), p. 460.

which opposes the flow of the electric current in the article, but chiefly by means of the arc which is formed.

It is highly important that not only can the electric pressure welding process be used for steel, but also for copper, brass, bronze, aluminium, zinc, and one can even weld together two different metals such as steel with malleable iron, mild and hard steel, copper and iron, &c.

Since articles of any size cannot be welded in one and the same machine, but only those between definite limits of size, resistance welding machines are unsuitable for ordinary work and only suitable on mass production work. Expensive welding machines have to be maintained for large and small articles, and, in addition, special fixing jigs, which have to be used for various cases and changed, are required for each shape of the various types of articles. The size of the article is unimportant. A section of 0·001 in.^{2} may be considered as the lower limit for the use of resistance welding, and the upper limit at about 110 in.^{2} for steel, but only about 3 in.^{2} for copper, because of the considerably greater conductivity of the latter. Up to the present, we have only discussed electric resistance welding as compared with forge welding. As a matter of fact, electric welding machines were only used at first for the welding of articles having a round, square, or rolled section. Later, spot and seam welding machines were developed from butt welding machines, and these are used for the welding of plates instead of riveting them. As far as the thickness of the plate is concerned the electric welding of plates is fixed by an upper limit of about 1⅛ in., whereas the lower limit does not exist, and even the thinnest plates may be joined to one another without being burned by the welding current, as easily occurs in welding by hand, either with the electric arc or with the welding torch.

As compared with riveting, the advantage of electric resistance welding lies in the fact that the strength of a complete joint produced in this way is always greater than a riveted one, since the weakening of the cross-section through rivet holes does not occur. With spot welded plates, when the construction is destroyed, fracture almost always occurs in the unwelded metal, whereas with riveted plates it usually occurs at the rivet holes. Resistance welding is superior from the point of view of cost, because marking out, drilling or punching of the rivet holes and the fitting of the rivets, &c., disappears.

WELDING MACHINES AND WELDING PROCESSES

Since resistance welding machines have not only got to bring the articles to be joined up to welding heat, but have also to take care of the welding process itself, that is, the pressing together of the articles, their equipment may be divided up into an electrical side and a mechanical side. The electrical equipment is fundamentally the same as for the various processes of electrical resistance welding, including flash welding, whereas the mechanical side differs in upset welding, flash welding, spot welding and seam welding, and is arranged to suit the type of article to be welded (on the one hand articles having a solid or profile section, and on the other hand plates).

The Electrical Equipment of Resistance Welding Machines.—The current strengths which are required for heating up the weld metal are extraordinarily high. They amount to 50,000 amperes and more. At the same time, corresponding to the low internal resistance of the work to be welded, through which the current passes, very low welding voltages are necessary. These amount to 0·5 to 8 volts. Low voltage current of this type at high current densities may best be produced by single-phase alternating current transformers. Since the current has always to be taken at high voltage from the existing main or from a special current generator, a *Transformer* is required for the electrical equipment of every machine, and this produces the required welding voltage.

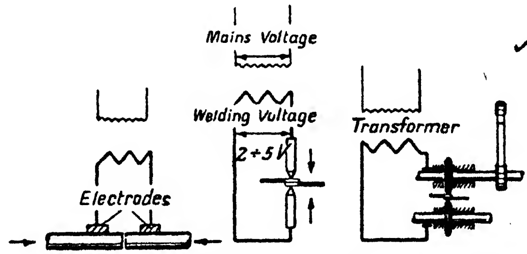


Fig. 1.—Butt welding Fig. 2.—Spot welding Fig. 3.—Seam welding

Figs. 1–3.—Lay-out of resistance welding processes

With a mains system using single-phase alternating current, the coupling-in of the welding machine raises no difficulty. Figs. 1 to 3 show the layout of the connexion of butt welding, spot welding, and seam welding machines to a single-phase alternating current main. With polyphase current mains, the conductors are wired between two phases and it should be borne in mind that, if such machines are available, they should be distributed equally on the three phases of the network in order to balance the three phases. Originally

power stations raised objections to the coupling in of single machines because they were afraid of disturbances due to unbalanced loading, especially with powerful machines. To-day power stations usually permit the coupling-in of single-phase equipment up to a load of 15 k.v.a. per phase, and recently individual stations have permitted them for trial purposes up to 100 k.v.a., on the condition that the machines will be put out of service if disturbances in the mains are set up thereby. Disturbances of this kind need not be feared. If single-phase connexion to the alternating current mains is not permitted, rotary converters will have to be installed. Since the single-phase generators of these converters are subject to high peak outputs, they should be carefully watched to see that they will stand up to high overloads. In order to maintain their voltage constant, it is advisable to provide voltage regulators. If direct current mains only are available, the current will, in any case, have first to be converted into alternating current by means of a generator or a single armature converter.

Not only may various weldable metals with varying conductivities have to be welded on one welding machine, but varying sections of one and the same metal, which frequently only differ slightly from one another in size, may also have to be welded. Hence fine control of the current strength, which increases with increasing section and increasing conductivity of the metal, is necessary. Hence every machine has a regulating device as an additional part of its electrical equipment. Regulation is always carried out on the primary side and is obtained by putting in or cutting out resistances. Stage regulators with links or plugging in switches are used which permit the current strength to be reduced to one-tenth of the maximum output as required. Choking coils are also used, but generally only for the welding of aluminium and brass, since they permit a fine setting to be made, but at the same time result in rather heavy power losses on load.

The welding current is fed to the parts of the article by *Copper Electrodes* which also serve as clamping jaws for the articles and effect the squeezing together during the upset process, as will be shown later. In upset and flash welding machines, four fixing jaws are provided on each butt welding machine. The current supply is usually effected as shown in fig. 4 to the two lower clamping jaws. Another design is that shown in fig. 5, in which the current feed takes place diagonally. In this case the current is compelled to distribute itself uniformly over each unit of area and this is an

advantage on uniform sections, but is a disadvantage on many irregular sections such as railway lines, since the thin web is then heated too quickly. In spot welding machines, the electrodes, between which the weld is formed spot by spot, are made rod shaped. The welding tips are brought together by means of pressure on a pedal lever and are subjected to a contact pressure. In some welding machines the electrodes are made in the shape of rollers and the plate which is to be welded is fed lengthwise between them.

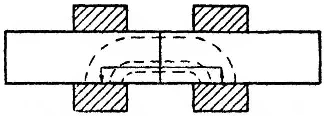


Fig. 4.—Current feed to clamping jaws, old type

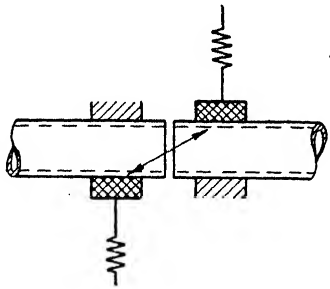


Fig. 5.—Diagonal current feed to clamping jaws, new type

All parts of the electrical equipment are well insulated and positioned in the frame of the machine.

The Mechanical Equipment of Resistance Welding Machines.—As has already been mentioned, resistance machines can only be constructed for a definite range of operation because of the variety of work to be welded. Depending on its shape and size, as well as on its conductivity, there are, therefore, a large number of types of welding machines. As was previously pointed out, they can only be divided into upset welding machines, flash welding machines, spot welding machines, and seam welding machines, but within these groups there are, in addition to various types, various sizes for ordinary welding work, and always a number of special types for definite purposes. Here we can only give a general survey.

Machines are constructed to work with either hand or foot drive and also constructed to be semi or fully automatic. The latter types of both kinds are, of course, only intended for pure mass production work. In addition, the machines may be made portable, transportable or fixed, depending on the purposes for which they are to be used.

In addition to the electrical equipment which has already been described, the fixing jig, the upset and pressure gear, and the mechanical equipment are of interest since they are the main parts of the machine. The fixing jig serves also as a device for feeding current to the work. In other words, it forms the electrodes. As was men-

tioned during the discussion of the electrical equipment, these are designed as clamping jaws, rods or rollers, depending on the type of process. Consequently the machines for the various processes must be treated separately in the following pages, and, at the same time, their supervision and the way in which the process is carried out will be discussed.

Upset Welding and Flash Welding.—In addition to the large number of special designs for special purposes, two basic types have been developed for the welding of solid sections and rolled sections. *Machines* are constructed with the opening between the fixing gear

Fig. 6.—Heavy type butt-welding machine of welded design with motor-driven fixing and upsetting gear

situated at the top and pointing upwards, or they are fixed at the front and lie horizontally. The latter are specially suitable for heavy and unwieldy parts, and their location in the upset gear is facilitated by this type of construction, but the former permits of a very simple construction. Fig. 6 shows a butt welding machine of the horizontal type, and in passing it may be mentioned that the design here is completely welded from steel. In this design the fixing and upsetting are carried out by means of a motor. The switchboard may be seen in the background.

In general, the following remarks may be made concerning operation. In the smallest machines, the upsetting is usually effected by means of a hand lever which permits of very sensitive control of the work.

With the medium sized machines the hand wheel is usual, even

though in this case a motor drive is frequently used. With heavy machines, on the other hand, an electrical, hydraulic or compressed air drive is employed.

Fig. 7 shows a special design of a butt welding machine for the electrical welding of chains. Butt welding machines have become extremely important for this class of work. The machine is semi-automatic.

As a rule, butt welding machines can be used for the upset welding as well as for the flash welding process. In these circumstances only the operation is different.

Fig. 7.—Semi-automatic chain welding machine

In *Upset Welding*, the pieces which have been previously machined are brought together so that they fit well up against one another. In spite of this, since the contact between the two butted sections is initially only point contact, the current is opposed by a high resistance at the point of contact, and hence the points of contact are intensely heated in a very short time. By skilfully pressing together the butting surfaces, which is rendered possible because of the softening of the points of contact, the current is always finding fresh points through which it can flow, and, because of the internal resistance of the article which is carrying the current, the section of the butting surfaces is heated more or less regularly to the maximum temperature at which the welding of steel takes place. When the required degree of heat has been obtained, the articles are pressed hard against one another so that an upset burr is formed at the welding point.

This upset burr, which cannot be avoided, is an external indication of all electric butt welds, and this is not only detrimental to the appearance, but often impairs the quality, and hence it must be removed by subsequent machining.

The mode of operation in the *Flash Welding* process is as follows: The articles which have to be welded are fixed in the clamping jaws

exactly as was done in the upset resistance welding process. The butting surfaces are brought into as intimate contact as possible, and the current switched on. The characteristic and essential difference between the two types of resistance welding lies in the fact that contact between the butting surfaces is not permanent, but is always being interrupted by a short to-and-fro movement of the clamping jaws, so that a temporary arc is formed along with a heavy shower of sparks. In this way, especially with complicated sections, the butting surfaces reach a uniform welding heat at all points in the shortest possible time. It is an essential property of the arc flame which is produced in this way, that irregular faces are melted down and perfectly parallel butting surfaces are produced at the same time. It is unnecessary to machine the butting faces as is done in upset welding. At the moment when the arc is not extinguished by the jaws being moved towards and away from one another, but remains "stationary", which is an indication that uniform and satisfactory heating has been obtained, the articles are brought together with a blow, the current being switched off at the same time. In this way all molten particles of metal and slag are forced out of the weld zone. They form a burr round the welding section. Just as the reinforcement was the external characteristic of articles which had been welded by the upset welding process, so is this burr a characteristic of the flash welding process. It may easily be removed by hammer blows after cooling. Slag inclusions are extraordinarily rare in this process. Perfect welding is assured by carrying the heating up to the melting-point.

Fig. 8

Fig. 9

Micro-photographs of an upset and a flash weld

The advantage of the flash welding process, as compared with the upset welding process, lies in the fact that, due to the " evening up " effect of the sparks, even without preparation and preheating of the butting surfaces, a uniform heating of low and high spots is obtained, and the inclusion of slag or the formation of cavities through gas blisters is avoided. This is of considerable importance in the welding of heavy sections, as may be seen from figs. 8 and 9. The flash welding process is very suitable for the welding of large sections as well as for castings and pipes.

In addition, high grade steels may be satisfactorily welded by means of the flash welding process. It is used in the production of

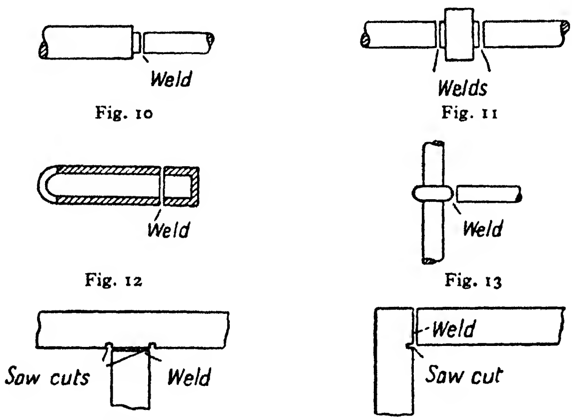


Fig. 10 Fig. 11 Fig. 12 Fig. 13 Fig. 14 Fig. 15

Figs. 10–15.—Preparation of various classes of welded articles for butt welding

cutting tools, turning steels, &c., and in order to weld high grade steel tips on to steel of lower quality.

As compared with forge and water gas welding, both upset welding and flash welding have the advantage that, in these processes, the heating does not take place from outside to inside, but in the reverse direction, so that the welder is in a position accurately to know from the state of the surface that the whole welding section has been brought up to the welding heat. In addition, as compared with forge welding, improved quality is obtained due to the circumstance that, with these processes, the air cannot act on the heated butted section and hence the absorption of oxygen and nitrogen from the air is prevented. Faulty welds are therefore much less frequent with the resistance welding processes than with forge welding.

It is necessary that the welding sections should, as far as possible,

be the same size otherwise the lighter article is heated more quickly than the heavier one. It is then subjected to the danger of burning before the heavier article has been brought up to the welding heat. If, by the choice of design, it is impossible to obtain butting sections which are approximately equal in size, special *Preparation* is necessary for the welding. In many cases this may be done by simple methods. Some examples of these are shown in figs. 10 to 15. In fig. 10 the heavier shaft has been turned for a short length with a projection of the diameter of the lighter shaft. In fig. 11 the welding of a shaft with a collar, and in fig. 12 the welding of a pipe, are shown. With corner joints (L, T and + shaped articles) one of the members is jumped up by a slight amount and the cross member is welded to the jumped up reinforcement as may be seen from fig. 13. This, however, is only possible with light sections. With heavy sections small saw cuts may be made, as in figs. 14 and 15, and these concentrate the welding heat at the point desired. If precautions of this kind are impossible, the welding must be preceded by a preheating of the heavier article which is to be brought to the welding heat. The preheating may be carried out with the machine itself if the fixing of the two articles to be welded is carried out, for example, as shown in fig. 16. The current is first switched on between the jaws 1 and 2 and switched over to jaws 3 and 1, or 3 and 2, as soon as red heat is reached. Butt welding machines are also built and these have a special preheating transformer for this purpose, which is coupled in to the circuit in parallel with the welding transformer. If the former contingency is not provided for, the preheating must be carried out on a special heating machine or in the smith's fire. In spite of all this auxiliary equipment, the process is useless for complicated sections such as T or U sections, or with pipes. Its inapplicability to castings is due to the degree in which the heat conducting conditions vary at different points in a thin section. Whereas points in a thin section fuse, the heavier ones are still too cold so that they do not weld together.

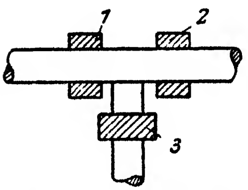


Fig. 16. — Preheating of welded articles of different sizes for butt welding.

Special attention must be paid to the use of good fitting *Clamping Jaws*, and to the correct *Fixing Length*. The shape of the clamping jaws must be exactly suited to the articles. Special clamping jaws must be provided for every shape and size. Working patterns for every case that may arise cannot be provided and hence, in figs. 17

to 22 a few of the types which are used for securing circular or crosspieces are given. The arrows indicate the direction of the butting pressure.

The *Fixing Length* is governed by the material and the welding section. Good conducting material is fixed over a longer distance, and material with a high electrical resistance over a shorter one. If two materials of different conductivities are welded together they must be fixed over different lengths. Provided that both sides have the same weld cross-section, the total fixing length is generally selected as 1·4 d. for low carbon steel, 1·2 d. for high carbon steel, 4 d. for copper, 3 d. for brass. For steel to copper the former is

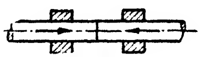


Fig. 17

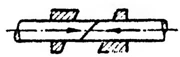


Fig. 18

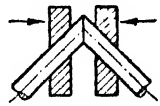


Fig. 19

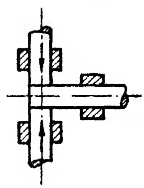


Fig. 20

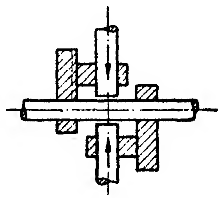


Fig. 21

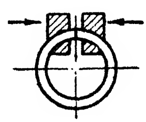


Fig. 22

Figs. 17–22.—The fixing of circular and square articles in the clamping jaws

fixed for a length of 0·7 d., and the latter for 1·8 d. In the welding of mild and hard steel the fixing lengths are 0·6 d. and 1·5 d. respectively.

In the welding process itself, special attention should be paid to ensure that the switching off of the current and the butting takes place at the correct moment. With automatic machines the butting process starts automatically at the right time. With hand-operated machines, it depends on the attention of the workmen whether any overheating of the weld material takes place. In this respect, it is very easy to make a mistake. When the exterior has apparently just reached the welding heat it is possible that the centre of the weld section has already been overheated, since the heat is the greatest there.

As the temperature of the welded work increases, there is an increasing loss of heat, part of which passes to the neighbouring parts, and part of which is radiated in the air. This takes place to

an extent which is greater the longer the duration of the weld, the greater the fixing length, the greater the weld section, and the higher

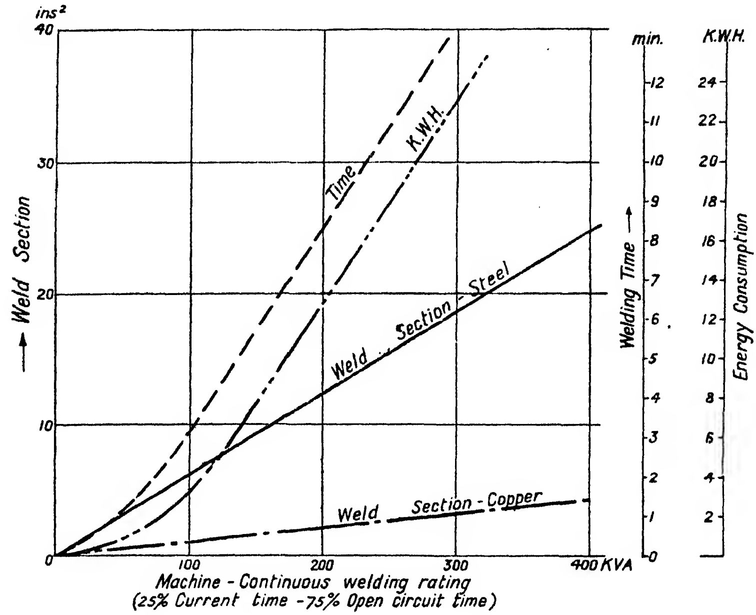


Fig. 23.—Time and energy consumptions for the butt welding of copper and steel sections

the heat conductivity of the weld material. These losses must be made good by increasing the current strength in order to obtain a temperature increase up to the welding heat. Accordingly, welding machines are so to be selected that their output is suitable for the weld section and the type of material and that as uniform a heating as possible is obtained so as to avoid heat and current losses.

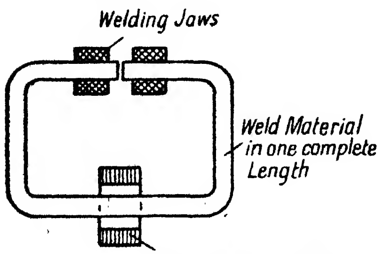


Fig. 24.—Choking the shunt effect in the welding of a closed article by means of a steel plate core ring.

The graphical illustration in fig. 23, which is given by a leading firm of specialists, gives some idea as to the *Choice of Size of the Machine.* It will be seen that metals which are good conductors of electricity, such as copper and brass, require very much higher quantities of energy than steel in spite of their lower welding tem-

perature. Hence welding machines should not be chosen too small for their maximum and continuous rating, and in these cases a safety margin should be added to the values given in this graph. Special reference must be made to the fact that in the welding together of closed members such as rings, buckles, &c., considerable power losses frequently occur. In such cases, therefore, a greater margin must be taken for the transformer output, the greater the welding section and the greater the circumferential length of the article. At the same time the shunt effect which occurs in the welding of such objects may be overcome by surrounding the article with an iron ring, as is indicated in fig. 24. This must not touch the article. It acts as a choking coil.

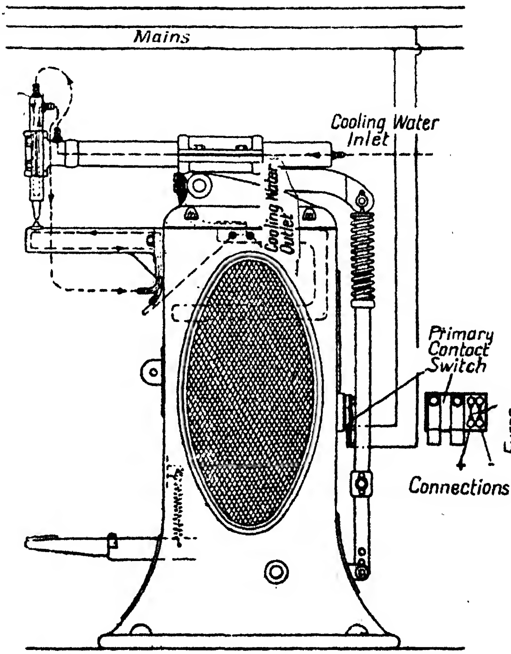


Fig. 25.—Spot-welding machine with the cooling water passage shown

Spot Welding

As is indicated by the name, spot welding serves the purpose of making a joint between metal surfaces by means of individual weld spots. It is especially suitable for joining thin plates. Due to the fine regulation, there is virtually no lower limit for the welding of such plates, whereas for economic and technical reasons the upper limit lies at a plate thickness of about 1⅛ in. Just like butt welding machines, from which they were developed, spot welding machines are built not only for normal work, but also for the most widely varying special purposes, but they do not attain the dimensions of heavy butt welding machines.

In *Spot Welding Machines*, also, two groups have been formed. The upper electrode is either moved in a vertical direction with a solid upper arm, or the whole upper arm is designed to pivot with

the electrode. The former construction is used more on machines having a very large or a very small reach, since it is difficult to fit a pivoting arm on these machines. The most usual type of construction is the latter. Fig. 25 shows the mechanical construction of a spot welding machine of this type, and this indicates the layout of an average machine with the water cooling shown dotted. As may be seen the rod-shaped electrodes are fitted in two electrode arms, the lower one, which may be dismantled, being bolted rigidly to the frame. The upper arm may be swung and its reach is adjustable. It is also arranged to pivot so that it may be brought up to the job in any desired position.

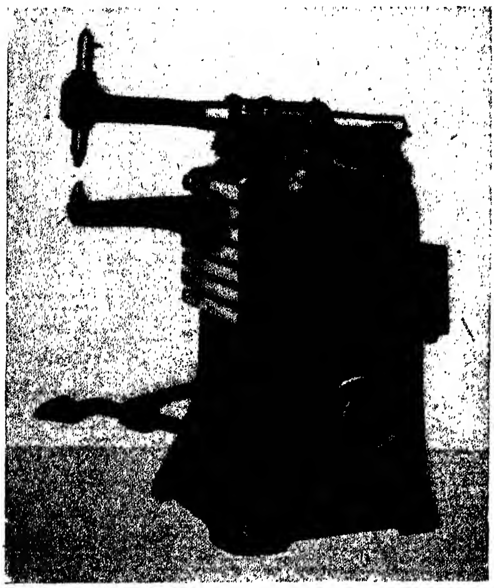


Fig. 26.—Spot-welding machine of the normal type of construction

The electrodes are water cooled. Since the lower electrodes have to be changed and the upper ones have to be lengthened or shortened to a corresponding extent by moving them, it is possible on every machine to lengthen the reach on the lever between definite limits and adjust it to the article to be welded. The reach, however, is limited since the arms are subjected to heavy mechanical stresses and have to carry high currents. With small machines the reach does not exceed 20 in., and with larger machines not more than 4 ft.

All processes of operation are effected by means of the pedal lever. By forcing the pedal lever down, the plates, which have been put in between the electrodes, are first pressed together. When the lever moves down farther the primary current switch is operated. When the high secondary current has heated the plates at the fixed spot to the welding heat, powerful pressure of the pedal lever concludes the welding process. When the lever is released the current is first switched off and then the weld material is released. The

entire welding process takes place extraordinarily quickly and only lasts a fraction of a minute.

It is absolutely necessary for the success of the welding that the welding time should be kept to within close limits, since, if the welding time is too short, unsatisfactory penetration is obtained, and if the welding time is too long the plates are burned. Therefore spot welding machines have recently in many cases been provided with an automatic switch. The switch ensures an absolute regularity of the welding work and one which cannot be obtained by hand. More-

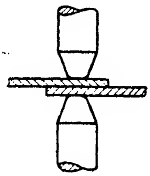


Fig. 27

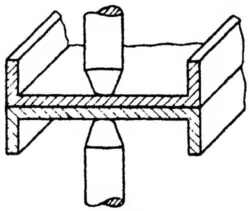


Fig. 28

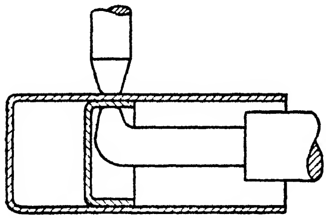


Fig. 29

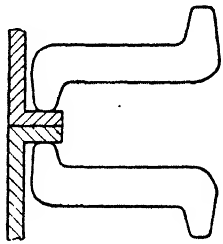


Fig. 30

Figs. 27–30.—Various shapes of electrodes for spot welding

over, it ensures a reduction in the welding time, protection of the electrodes, and considerable savings in current. Its advantages are therefore so great that one may take it for granted that in the future all spot welding machines will be fitted with it. The switch may be operated either by the primary or the secondary current. The switches are designed some as pure time switches and others as pure maximum current switches.

Fig. 26 shows a spot welding machine of the normal type of construction.

Further, it should be noted that scale and rust on the plates make it impossible to obtain a satisfactory weld. For spot welding, therefore, only descaled plates are employed.

Black plates, which are not completely clean, are cleaned with a

sand blast or by pickling in acid. Galvanized, tinned and lead-covered plates may be spot welded. It is also possible to weld various thicknesses or very thin plates to a heavy backing plate, such as a square section about $\frac{3}{8}$ in. thick, or to weld complete bundles of plates together.

The shape of the weld and the choice of the welding spots must be suited to the *Shape of the Electrodes.* In normal plate work and in the welding of sections, rod-shaped electrodes with slightly coned tips may generally be used, as shown in figs. 27 and 28. For special cases, bent or angle electrodes are required, as shown in figs. 29 and 30. In the welding on of studs, the lower electrode is so made that the stud may be let into it for about $\frac{1}{32}$ in., as shown in fig. 31. For this purpose there are a great variety of shapes of

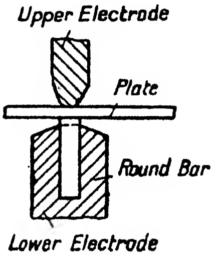


Fig. 31.—Electrodes for spot welding for the welding of stud-shaped articles

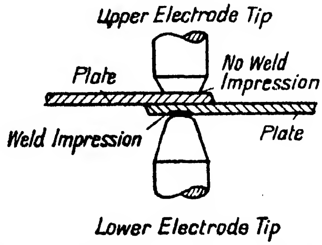


Fig. 32.—Spot welding electrodes for impress welding on one side

electrodes, depending on the type which is required, and the figures only provide suggestions for the way in which they can be made. If, from considerations of safety, a smooth surface is required, the arrangement which is shown in fig. 32 must be selected since the electrodes leave welding recesses behind. The loading area of the movable electrode is large and acts on the face where the welding recess is to be avoided, whereas the opposite electrode is made correspondingly more pointed.

Good cooling is absolutely necessary for a long working life of the electrodes. In addition, it is necessary to clean the electrodes from time to time with emery paper or with a light file, and to free them from scale and copper oxide which forms on them during working. In spite of this, the electrodes are subjected to fairly heavy wear, so that they have frequently to be replaced.

The graphical representation in fig. 33 gives an indication of the approximate *Time Required* and *Energy Consumption* for various plate thicknesses. From this it may be seen that a welding time

of one second is required for a plate of about $\frac{1}{32}$ in. cross-section. With thin plates it is possible for one workman to make 15,000 welding spots in a working shift. The figures given in the graph only apply to accessible articles. For inaccessible welded articles, such as cylinders, buckets and pipes, there are several important retarding factors so that corresponding margins must be added to the figures. In addition, in spot welding, the energy consumption increases with the increasing reach on the electrode arm.

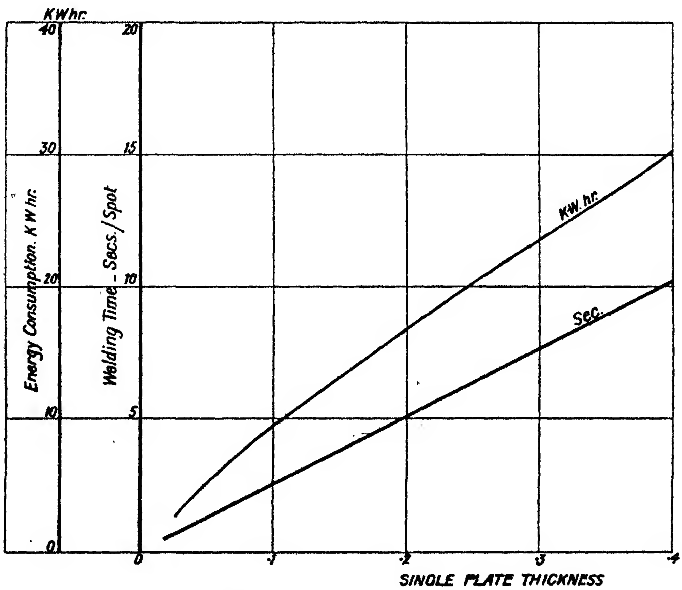


Fig. 33.—Time and energy consumption on spot welding

It is therefore advisable not to choose the reach of the arm greater than the shape of the weld entails. A short leverage is also desirable because the mechanical stress increases with the length of the arm. Finally the output is affected by the amount of iron which is situated between the electrode arms. With a large quantity of iron welding requires a greater amount of energy than with a small quantity. The curves in the figure, therefore, only apply for a medium reach of the electrode arms and if no large quantity of iron lies between them. On the other hand, the thicknesses of the separate plates have no influence on the welding time. This is determined by the total plate thickness.

The arrangement of the welding spots may be as desired. As is

required by the design of the welded work, the welding spots may be arranged in a row as in riveting, or in several rows, or they may be staggered, so that we have series, chain, or zig-zag spot welding.

*Seam Welding.**—In addition, with spot welding, continuous seams may be made by letting the weld spots overlap one another so as to get water-tight or oil-tight joints. The process, however, is costly. For this reason the spot electrodes have been replaced by roller electrodes, by which means the welding speed is considerably increased. In this way *Seam Welding Machines* were developed from spot welding machines. In by far the majority of cases the rollers are driven mechanically. In other respects the construction of seam

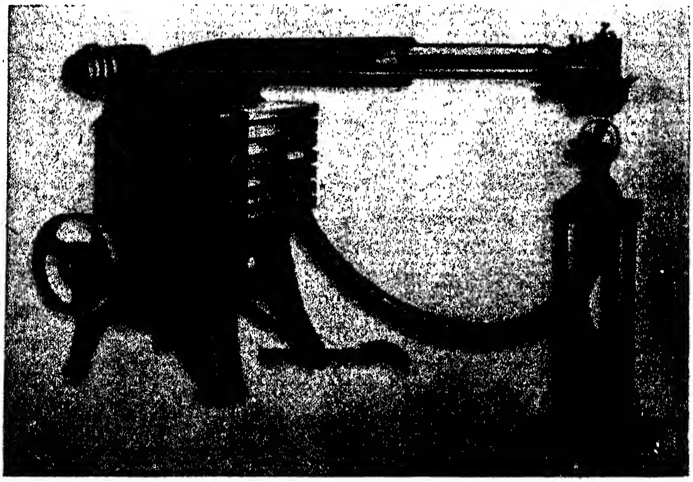


Fig. 34.—Seam welding machine for the welding of heavy members

machines is similar to that of spot welding machines. Fig. 34 shows a seam welding machine of this type. Instead of two rollers, which are fixed like the rod electrodes, one in a fixed and the other in a movable electrode arm, only one roller is used in the upper arm, whereas the lower arm is constructed in the shape of a rail. The article remains stationary on the lower arm during the whole welding process, whereas the upper arm, which is guided in a sliding carriage, guides the roller step by step over the seam which is to be welded. When the work is finished, the roller returns to its initial position at an increased speed and without carrying current. This arrange-

* Roth, "Concerning the Present-day Position of Electric Resistance Seam Welding", *Technisches Zentralblatt*, Vol. 39 (1929), p. 37.

ment is preferred for very large and very small runs of weld. A machine of this type is shown in fig. 35.

In general, there is a large number of special types of seam welding machines depending on the class and size of the article, and these cannot be discussed in greater detail here.

Although the idea to replace spot electrodes by rollers in order to obtain a continuous seam may appear easy, it is difficult to carry out the process. Seam welding machines had to pass through a long course of development before these difficulties were overcome.

The *Driving of the Rollers* and the feeding of the current has been achieved in a great variety of ways. The rollers were originally moved continuously while carrying current, and later with single interruptions in current, or they were allowed to remain stationary for a time with the current switched on and then moved on further with the current switched off. In many cases, backward movements of the rollers were arranged. Eventually a return was made to the original way of guiding the rollers. The reasons for this were as follows.

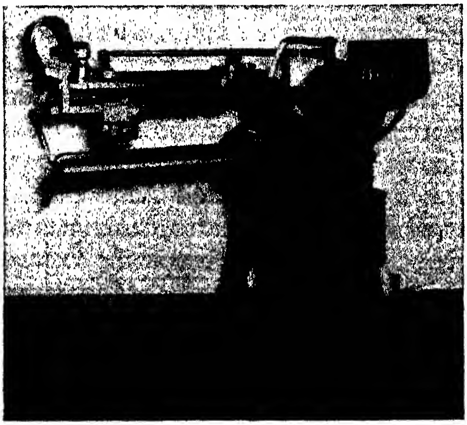


Fig. 35.—Seam welding machine with travelling roller and bearing rails

The rollers have not only to carry out the welding process, but they have to feed the plates forward. On account of this feeding the base material is torn. When the rollers were originally fed forward with the current continuously on, the following undesirable state of affairs was encountered. Since the base material did not cool quickly enough a hot spot remained behind the seam, which had just been pressed together by the electrode, and, under this tearing action called into play by the feeding, the spot was easily torn apart again. Going over faulty places of this kind for the second time is not only expensive in time but useless, because the place has usually acquired an oxide skin due to the influence of the air, and this hampers subsequent welding. In addition, the same phenomenon which has already been mentioned in spot welding occurred, namely, an arc is formed, which causes holes to be burned in if the electrode is

lifted from the welded spot while carrying current. The seams were extraordinarily bad if the surfaces of the plate were not very clean. An increased heat development then resulted which favoured the fracture of the seam. At the same time rapid fouling of the rollers occurred.

For this reason a change was made so that the seam welding process was as similar to the spot welding process as possible. With this process, better results had been achieved from the beginning and the seam was made in a similar way by means of separate spots by allowing the roller to stand still for a short time during the passage of the current and during the welding process. After a single weld had been made the rollers advanced one step further with the current switched off. The process is known as "*Step Welding*". As a matter of fact, the process introduced a considerable improvement in the welded joint, but it was accompanied by losses in time. The welding output, as compared with the original process, was decreased. At the same time, even to-day there are a large number of seam welding machines built on this principle. A subsidiary of step welding is the "*Step by Step*" *Welding Process* in which the rollers are allowed to advance for a distance forward with the current off so that the plates are pressed together. The rollers then change their direction of movement and weld with the current on, passing backwards over the length which has just been traversed. By means of the following forward movement which takes place and which is made with the current switched off, the welding place, which is still warm, is again traversed and compressed, after which the process is repeated. A great deal has been expected from this process and it has done excellent work, but in spite of this it has not been adopted to any extent in practice, because the welding output was lowered still farther than with step welding. It is only mentioned here for the sake of completeness.

Other improvements which were used to carry out seam welding by means of individual spot welds have not led to any practical results. Among these attempts has been welding with a uniform, *Continuous Travel Roller*, but with a rhythmically interrupted current. In this case the difficulties with the switchgear for the current interrupter were too great.

Using the process employing a non-interrupted current with a continuous feed roller for the welding of thin plates, it was found that, as the speed of feed was increased for reasons of economy from the usual 3–6 ft./min. to two or three times this amount, better seams

were obtained, not worse. The result has been that to-day we have returned to this process for thin plates. The explanation of this curious phenomenon is to be found in the peculiarities of alternating current in which the current during one period alternately reaches a maximum and then falls to zero. In each period, therefore, as soon as the current reaches the maximum value, two welding points, between which there is a natural interruption in current by the passage of the sine curve through zero, are made. With a feed speed of 19·5 ft. these points are situated about $\frac{1}{32}$ in. apart. Hence, with repeated welding under natural conditions, the same result is achieved as with a reduced speed employing artificial interruptions in current.

In this way, seam welding has returned to its starting-point along the path of well worked out and ingenious processes.

It should always be borne in mind that in the rapid welding process the slightest uncleanliness of the plates or the rollers and every variation in current or electrode pressure can give rise to faults. The process is therefore restricted to plates up to about 18 gauge thickness, while for heavier plates up to $\frac{1}{16}$ in., it is preferable to use the welding process with interrupted current.

With this process also it is well to take care to have well-cleaned plates. The opinion that black plate or plate lightly covered with scale can easily be welded with machines employing the step welding process has proved to be unsound in practice. In recent times, automatic fusion welding machines with metal and carbon electrodes have come into competition with seam welding machines, after successful attempts had been made with the former to increase the welding speed by a very large amount, as compared with hand welding. Especially for heavy plates, this type of fusion welding is superior to seam welding.

It should be mentioned that flash welding machines, in which the plates are fixed between two cross pieces which serve as clamping jaws and electrodes, have recently been constructed for seam welding. These machines, however, are only likely to have a future here and there, where large numbers of the same type of seam have to be made on thick plates, since, because of their construction, they are too costly.

The Application of Resistance Welding Processes

Upset and flash welding are chiefly used in the welding of heavy objects, which were previously made by fire welding in the smithy. Articles of this kind are, for example, railway buffers, carriage tyres, vacuum brake shafts, cranked shafts, shafts provided with collars, angle joints, and, especially where flash welding is used, for boiler tubes, tools of high-grade steel and for copper wire, &c. Upset welding or flash welding has proved very advantageous in the manufacture of very heavy forgings such as the base rings on locomotive fire boxes, crank shafts, &c., as well as for chains, as was mentioned in the description of upset welding machines.

Fig. 36.—Electric rivet heater with multiple settings

The application of spot welding and seam welding in the plate industry is extraordinarily varied, and also in the manufacture of sewing machines, typewriters, and in the manufacture of arms. For example, the following articles may be manufactured by spot welding: rollers, plate chimneys, steel furniture, hinges, parts for locks, cooking utensils, scoops, toys, lamp shades, typewriter parts, gun parts, pulley discs and many others. In the construction of motor cars, spot welding has quickly found a large range of application.

Seam Welding primarily serves for the joining of thin plate which was previously carried out by riveting, folding or hard and soft soldering. In addition to the welding together of straight smooth plates, where strength is of no importance, pails, cans, pipes, &c., are welded in this way.

Electric Heating Machines

Electric heating machines are closely related to resistance welding machines. Since electrical heat is suitable not only for welding purposes, but for the direct heating of articles, butt welding machines are essentially capable of use for this purpose as so-called electric

forges. Since their use for this purpose, however, is strictly limited, special designs have been made for individual cases which frequently occur, such as for heavy forgings, tyres and above all, for rivets.

Fig. 36 shows a rivet heater of a recent type of construction which may be used for heating two rivets at the same time. In order to fix rivets of various lengths without adjusting the holding jaws, the electrodes are separated from one another in stages. The rivet is put in between the rivet heating electrodes by pressing on the pedal lever. It is in the control of the operator to heat the rivets as he wishes, that is, he can heat the end of the stem to a welding heat or he can heat the stem and the head to a welding heat, and so on, or he may interrupt the heating process at any time and start it again.

Circulating water cooling is usually employed for cooling the electrodes. In the rivet heater illustrated, natural air cooling is provided in order to make it independent of water inlets and outlets.

Electric forges save coal and material and ensure a 90 per cent consumption of heat as compared with 10 per cent in the smith's fire.

CHAPTER IV

Aluminium Thermit Welding

The process, which is referred to as aluminium thermit welding or after its inventor, as Goldschmidt thermit welding, is based on the great affinity of oxygen for aluminium. With oxygen, aluminium forms alumina and is obtained from this material by means of heavy electric currents with the high formation of heat and the separation of oxygen. Conversely, aluminium combines with oxygen to form a hot slag, artificial corundum, and temperatures of about 5500° F. (3000° C.) are developed when finely divided metallic aluminium is mixed with iron oxide and the mass ignited. The pure wrought iron, which is set free by the oxygen from the iron oxide, separates out underneath the slag.

Goldschmidt used this reaction in developing a special welding process. Depending on whether one employs the hot molten steel for filling up a weld or the hot slag for fusing the butting surfaces of two articles which are to be joined to one another, which have then to be pressed together and welded by means of a pressure jig, one has to deal with fusion welding or with pressure welding. For special purposes a combination of the two processes is used.

For this reason aluminium welding has not been treated under the fusion welding and pressure welding processes, because it has no great similarity to either. This special process will now be discussed separately.

Thermit.—The mixed mass which was mentioned above, consisting of iron oxide and divided aluminium, which is used for carrying out the aluminium thermit process for welding purposes, is supplied under the trade name " *Thermit* ". It is neither explosive nor inflammable, and it may be heated to red heat without igniting. A distinction is made between " Black ", " White " and " Red " thermit. However, this nomenclature has nothing to do with the appearance of the three kinds. The only difference between the kinds is that, depending on the purposes for which

they are to be used, they provide a more or less pure iron or more or less heavy flowing slag. "Black" thermit is for repairs and rail welding, "white" thermit only for heating articles, "red" thermit is used for the butt welding of pipes. Consequently, in "white" thermit the slag is heavy flowing, and in "red" thermit the iron is of low purity.

The composition of thermit corresponds to that of a mild steel with a strength between 20 and 24 tons/in.^{2}. One lb. of thermit supplies $\frac{1}{2}$ lb. of iron, and $\frac{1}{2}$ lb. of slag. The quantity of molten iron, however, may be increased by the addition of small spheres of iron, and its mechanical properties may thus be influenced. At the high temperatures which the thermit develops, additions of this kind may be permitted up to 50 per cent of the thermit mass. The addition of ferro-manganese, ferro-manganese silicon, and Spiegeleisen give the thermit greater density and a composition which is more like steel. The temperature of the iron which is obtained from mixtures of this kind is naturally lower than that from the pure thermit iron.

For igniting the thermit an ignition mixture is supplied. A quantity of ·1 to ·15 oz. of this is sufficient for starting the reaction of as large a quantity of thermit as is desired.

Welding Plant.—The equipment which is necessary for thermit welding is relatively simple. It consists of a so-called special crucible or tapered crucible, which is also termed a tapping crucible, in which the thermit is ignited, and, when pressure welding is employed, of a clamping and pressure jig which is arranged to suit any given purpose. Both sorts of crucible consist of a steel plate casing which is lined with magnesite. Special crucibles are simple plate crucibles in five sizes from 3 to 45 lb. The taper or tapping crucible is supplied in 12 sizes from 5·5 to 750 lb., as shown in fig. 1. Fig. 2 shows, enlarged, the tapping hole of the crucible which is ready for welding. At the base a magnesite block *d* is fixed in which is situated an interchangeable thimble which contains a hole for the tapping pin *f*. Sealing is effected by means of a sealing plate *c*, under which is placed an asbestos disc *b*. The tapping pin is so fixed that it does not touch the asbestos disc. The iron plate is secured by a light blow from a hammer shaft, and on the top of this is placed a layer, $\frac{3}{16}$ to $\frac{3}{8}$ in. thick, of coarse dry magnesite sand or powdered artificial corundum. The thermit is then put in, and on the top of this is sprinkled as much of the igniting mixture as will go on the tip of a knife. After the ignition a plate cover *h* is put on. When the thermit mixture has been decomposed, and this requires about 10–20 sec.,

the pin *f* together with the pin lever *g* is raised, so that the thermit iron can flow out, followed by the slag.

In special crucibles, emptying is achieved by tilting the crucible so that the slag flows out first, followed by the iron. The clamping jigs

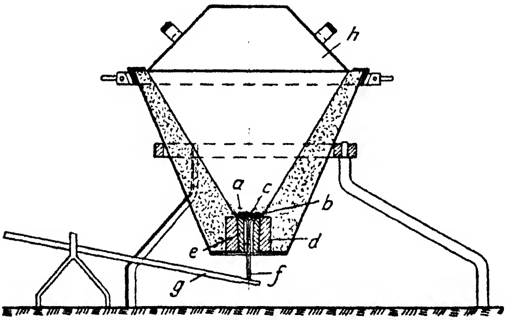


Fig. 1.—Taper crucible for thermit welding

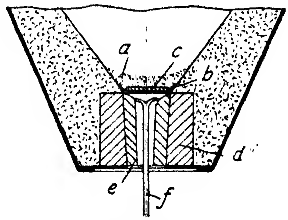


Fig. 2.—Tapping opening on taper crucible

a, Magnesite sand; *b*, asbestos plate; *c*, steel plate; *d*, magnesite block; *e*, tapping thimble; *f*, tapping pin; *g*, pin lever; *h*, plate cowl.

which are required in pressure welding will be described during the discussion on the application.

Making the Aluminium Thermit Weld and its Uses

Aluminium thermit welding has been used in:

1. The repair of steel castings, iron castings, and forgings.
2. The building up of rolling mill journals.
3. The butt welding of pipes, bars, &c., and the local heating of steel structural members.
4. The welding of rails.

Small flaws in castings, such as blisters, holes and faults in appearance, may be easily removed in the way indicated in fig. 3 by using a special crucible. The slag must be carefully removed and the article well heated. The hot thermit iron melts the faulty places and cools down, making an excellent joint with it. For large repairs a special crucible is preferable. For example, gear wheels are welded in the manner shown in fig. 4. The middle tooth shows the preparation, the left-hand one the welding, and the right-hand one the finished job. In addition, pressed supports, anvil blocks, &c., are welded.

If two fractured pieces are to be welded together, the fractured

surfaces must be carefully cleaned and the fracture itself so widened that room is made for the intermediate cast. In addition to strengthening the weld zone, the thermit iron should form a reinforcement or strap round the fracture. Consequently a surrounding cast is made from ½ to 2 in. thick. The mould which has to be made consists of refractory sand, which

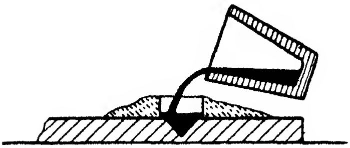


Fig. 3.—Repairing small flaws in castings

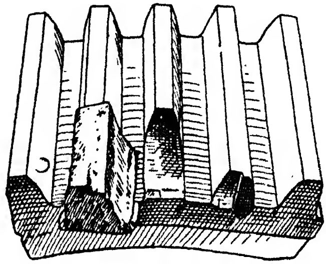


Fig. 4.—Repairing a pinion

should be carefully dried. The process may be seen from fig. 5. The process has been used particularly on ship repairs. For example, the stern posts of ships are welded in this way.

The aluminium thermit process has the same advantages in the repair of castings as the hot electric welding process, since with both processes broken articles, or those which are no longer useful, may be repaired. There is, however, the drawback, as with cold electric welding, that the transition zone of cast iron and thermit iron becomes very hard, and is therefore difficult to machine, because after the original heating of the article relatively rapid cooling takes place after casting. The low silicon content of the cast iron and the high manganese content of the thermit iron intensify this effect still further. In aluminium thermit welding there is also the danger, which exists to a greater extent than in cold electric welding, that, due to the local heavy heating during casting, especially if the article is not preheated sufficiently, stresses are set up which result in the formation of fresh cracks on cooling. Consequently it is seldom used for the repair of castings.

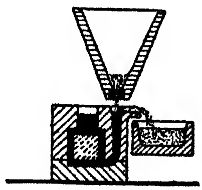
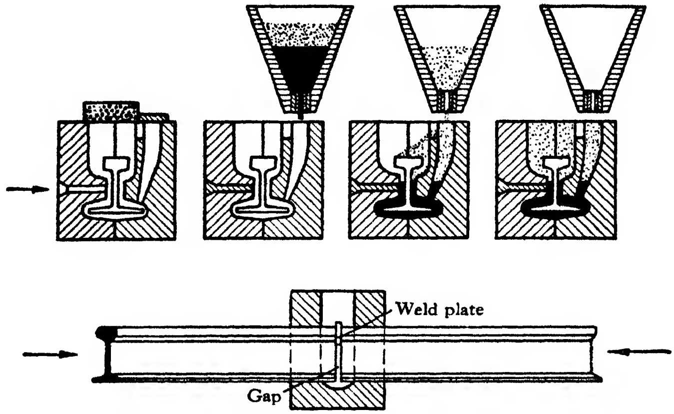


Fig. 5. — Welding of articles made of plate

The thermit heating process has also been used for tensioning slack diagonals in bridge construction.

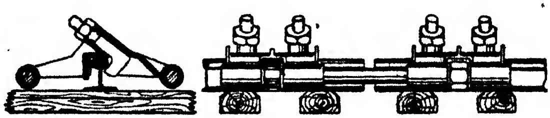
Aluminium thermit welding has found by far its greatest use in the welding of railway lines, especially those of electric tramways, but recently, to a very large extent, in permanent-way work. The

rail joint is the weakest point of the whole construction, and this is the cause of the greater part of damage to track. Since one is definitely limited in the length of rails because of methods of manufacture and questions of transport, in order to reduce the number



Figs. 6–10.—Rail welding with the combined processes

of joints, several rails have been successfully welded together by the aluminium thermit process. A combined process of pressure and fusion welding is generally employed, and less frequently the fusion process is used if the rails have already been laid in concrete. In the combined process, the quantity of thermit is so measured that the molten thermit iron only flows round the bottom flange and



Figs. 11 and 12.—Clamping jig for rail welding

the web, and on cooling forms a strap round these, while the hot slag softens the top flange, as may be seen from figs. 6 to 10. At the same time, the welding of the top flanges, with an intermediate layer of mild iron, is carried out by butting the two together with the clamping jig shown in figs. 11 and 12. It is necessary to preheat with benzine. The process cannot be used for rails which have already been laid in concrete. In this case a cast is put round the bottom flange and the web only, by means of the fusion process.

PART II.—APPLICATIONS AND TESTING OF WELDED JOINTS

CHAPTER I

Introduction

The newer welding processes, in addition to replacing the older pressure welding and forge welding processes, as well as brazing, have principally replaced folding, riveting and screwing for the joining of plates. In addition, they make it possible to manufacture objects in welded steel construction which were previously made as castings.

The process of welding will clearly only be adopted for cases where advantages are to be achieved. The rapid and many-sided development of welding technology proves that this is the case in almost all fields of engineering. On the one hand, manufacture is cheapened in most constructions and consequently larger economies are obtained with the new process without the quality of the product suffering thereby. On the other hand, savings in weight, which are of considerable importance, may frequently be realized. The quality may even be improved. Many objects manufactured by welding are less sensitive in service to stresses and wear so that the maintenance costs are reduced. Repair work will always be easier than formerly and many repairs only became possible with the introduction of welding.

Naturally the advantages of welding are not equally great in all the various fields of application. In every case, they will be increased the more the welding construction suits the peculiarities of the weld seam. The new technology has created a large number of new possible solutions. At the same time, it has introduced new problems and new conditions for those who are carrying out this work. Numerous mistakes have been due to the fact that riveted

designs were adopted and used for welded constructions without being modified and at least as many mistakes have been due to the welder, the works engineer, and the accepting official not being sufficiently conversant with welding technique.

It is therefore a primary necessity in welding that a skilled personnel should be employed which should be entrusted with all matters pertaining to this work. The designer must know how he should position his welds and what process he ought to select so that high quality may be obtained and large savings in material and working time may be achieved.

The works engineer must primarily be capable of making the correct choice of equipment and machines and of taking great care in their maintenance. In many cases the local conditions will have an effect upon what equipment and what machines are to be preferred. In addition, the works engineer should supervise the work of the welder and be able to give him the necessary advice. In many cases he may have to train welders himself because of the present scarcity of good welders. It cannot be admitted any longer that a welder should be left to himself as was previously possible. Now that the welding of the most difficult designs has been undertaken, skilled works supervision must be specified as the principal requirement for the success of the process.

The accepting engineer must primarily be in a position to judge the welding work which has been supplied. This is more difficult than with any other job because very frequently, with a finished weld seam, one cannot judge the internal state from the external state. The seam may appear very good externally, but inside it may contain various faults such as bad junctions, slag inclusions, hollow spots, burnt spots and insufficiently welded places, &c. In these circumstances, a bad weld forms a much greater source of danger than a badly fitted rivet, since bad welded joints frequently hold out for a long time in service and deceive one as being well made and then perhaps, after years, give rise to an accident. Consequently testing methods are of considerable importance in welding engineering.

Due to the extraordinarily rapid development of welding processes, too small a number of suitable and experienced engineers is available. Luckily, High Schools, as well as Technical Schools, have energetically taken up the training of welding engineers in recent years, so that it is to be hoped that this shortage will be removed in the near future.

Of equal importance to the training of an experienced body of engineers is the care which should be taken in guiding the *Training of the Welder* into new channels. One must be on one's guard against entrusting work, for which extraordinarily high quality is demanded, to unsuitable people. In general new welders to-day are taken from the ranks of metal workers and scientifically trained in works which have considerable experience and a suitable personnel available. Many have been trained, both practically and theoretically, by the training courses which have been established in recent years, e.g. those of the Verband für autogene Metallbearbeitung (The Association for the Autogenous working of Metals), in various towns and firms, in the State Railways, and in technical schools. In order to keep away unsuitable personnel the Gesamtverband Deutscher Metallindustrieller (United Association of German Metal Industrialists) in conjunction with the Fachauschuss für Schweisstechnik (Technical Committee for Welding Technology) of the Verein deutscher Ingenieure (Association of German Engineers) and the Verband für autogene Metallbearbeitung (Association for the Autogenous Working of Metals), has formed a new working Committee for the training of welders, which is to set up standards for the training and testing of welders in order to obtain a uniform basis on which to work.

The ultimate aim of the Working Committee is to introduce manual instruction during apprenticeship years. This has already been started with success in various places. This procedure, however, is to be regarded as a goal of the future. Neither during the present nor in the next few years will the large requirement in welders be adequately covered, in addition to which there are, at the present, certain difficulties in the carrying out of the evolved plan because of the old rights of trade unions. For this reason the deficit must first be made up from the ranks of allied tradesmen.

From the regulations which are shortly to be expected, the accepting party will not only be provided with a means of keeping away unsuitable contractors and welders from highly responsible jobs, but a movement will be started in the direction of uniform conditions for all works which are engaged on welding work.

CHAPTER II

The Application of Welding Technology

Before we discuss in detail the quality of the weld seam and the economic advantages of welding, it would appear advisable to give a short survey of the field of application. In this way it will most easily be seen that the advantages of welding technology are of the most varied kind. In many cases the high quality of the product will be important, as this ensures high strength or long life. In other cases cheapness of production will be the deciding factor or the savings in weight which have to be made will afford some special advantage.

The following examples and the diagrams which are included cannot be considered as exhaustive among the extraordinarily large number of applications of welding. We will, therefore, refer to the " Ausgewählten Schweisskonstruktionen " (Selected Examples of Welded Construction), published by the V.D.I. Verlag, which are appearing as a continuous series, arranged according to the fields of application, and which contain a large number of important examples.

The first field to be occupied by welding was *Repair Work.* Even to-day it is far away the most important application, and one which provides the greatest economic advantages, and in which welding has become almost indispensable. Savings are primarily to be found in the fact that a large number of fractured, cracked and worn parts may be made serviceable at low cost and restored to their full value. Repair work is carried out to-day either by welding up fractures which have been well cut out, as shown in fig. 1, or by the welding on of patches or by building-up welding. The last method serves for filling up corrosion seams or for the strengthening of worn machine parts such as trunnions, shafts, guide blocks, &c. By means of building-up welding, and by the use of a hard welding wire, one may simultaneously ensure that the abrasion strength of the repaired article is increased, and hence wear is kept within narrow limits. The cross head guide shown in fig. 2 will serve as

an example. Frequently, to-day, a new member is provided with a hard built-up surface of this kind, as, for example, the cutting edge of excavator shovels, &c.

Another field in which welding has been used from the early days is in the *Construction of Containers.* The advantage which is afforded in this field by welding is generally to be found in the economic production of the joints which may be made more cheaply

Fig. 1.—Welded tyre on a locomotive

Fig. 2.—Abrasion resisting built-up weld on a cross-head guide

by welding than by riveting. In addition, however, for containers for liquids, gases, and steam, it is due to the fact that a good weld is absolutely tight and remains tight, whereas a riveted seam frequently gives rise to continuous maintenance. Welded containers of this kind are welded in the smallest sizes, as for tipping skips, up to the greatest sizes, such as gas holders. Welding is almost entirely used for containers for the chemical industry, and stainless steel, copper, or aluminium are generally used in order to prevent destruction from external influences. Welded seams may also be made resistant to rusting. (See figs. 3 and 4.)

The same remarks apply to the manufacture of pipes. Welding makes it possible to make simple welded connexions which are easier to keep tight than spigot and flanged joints. For branches

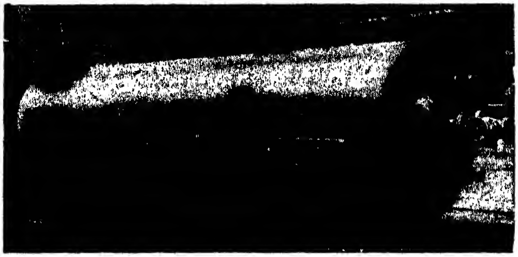


Fig. 3.—Welded boiler for the chemical industry

it is unnecessary to turn to expensive castings. (See fig. 5.) Erection is considerably facilitated and simplified.

In *Pipe Welding*, the best workmanship is absolutely necessary. This is difficult since, on the one hand, welding has to be carried

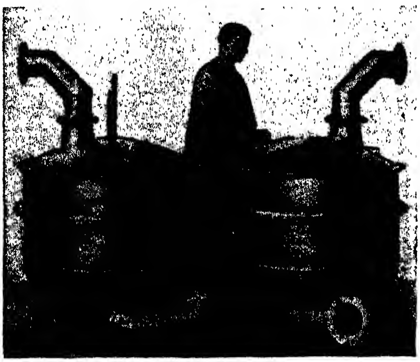


Fig. 4.—Welded copper vessel for the chemical industry

Fig. 5.—Shaped pipe

out in all positions, both in the vertical direction and overhead, and, on the other hand, the running through of the filler material must be avoided, since in this way the pipe cross-section is reduced and resistances to flow are set up. Disintegration and erosion are favoured by the so-called welding " rag " in the pipe. A large piece of work in the field of pipe line construction is the long distance gas line from the Ruhr to Hanover. The experience which was obtained with a large piece of work of this kind led to the drawing up of

" Richtlinien für die Herstellung von Schweissverbindungen von Gasrohrleitungen von mehr als 200 mm. Durchmesser und von mehr als 1 atü Betriebsdruck " (Draft Specification for the manufacture of welded joints for gaspipes of more than 200 mm. diameter (8 in. approx.) and more than 1 atmosphere working pressure), which are published by the Fachausschuss für Schweisstechnik (Technical Committee for Welding Technology of the V.D.I.).

In addition, pipes of large size may be manufactured as welded designs from plate more cheaply than the previous seamless type.

The *Tube as a Constructional Element* has acquired a further importance because of welding. On account of its high buckling strength, a considerable saving in weight can be obtained by tubular construction as compared with section construction. Further savings in weight may be obtained by dispensing with all connecting members. The result is that many joints are easier to make by welding tubes than by welding sections.

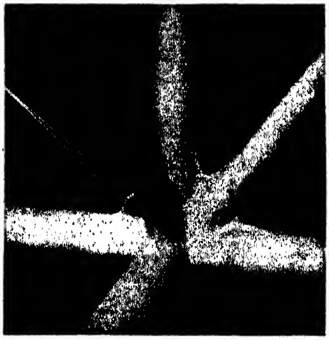


Fig. 6.—Tubular joint on an aeroplane

In *Aeronautical Construction*, where savings in weight play an important part, welding is therefore being used more and more. (See fig. 6.)

It seems doubtful whether tubular constructions for the building of steel structures, such as the roofs of buildings, bridges, &c., are an advantage since the extra cost of the more expensive seamless tubes, as compared with the much cheaper rolled sections, cancels it out. In this case, savings in weight are hardly likely to be a deciding factor.

Welding has found a most extensive application in the *Construction of Motor Cars*. A very great opportunity is provided for electric resistance welding, but fusion welding is also used. The following examples may be mentioned. The manufacture of rear axle shafts, cardan shafts, and differential housings, the front axle, portions of the body, such as the side members, roof, &c. Since we are dealing almost exclusively with mass production work, flash welding and spot welding are the most important. In addition, in the *Light Industries* these processes have acquired considerable importance.

Savings in weight and cost may be achieved in *Shipbuilding* by

means of welding. The Admiralty has proceeded very logically with this work, and has progressively abandoned riveting in its con-

Fig. 7.—View of inside of a welded barge

struction. The savings in weight on this work are of considerable importance since the storage capacity of a ship may be considerably

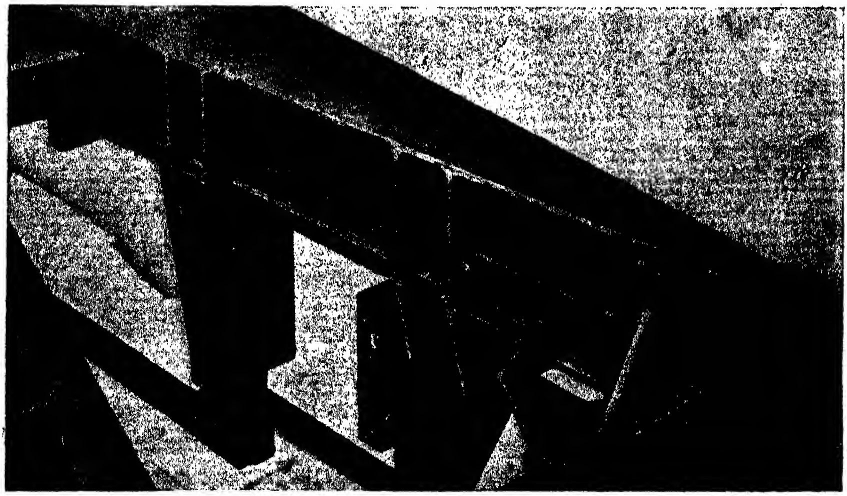


Fig. 8.—Welded bogie of a main-line carriage

increased for the same weight. In merchant shipping and barge work also, welding is beginning to occupy an important place. (See fig. 7.)

It is only in recent times that we find welding being used for

Railway Work and for transport work. In this field, considerations of safety make important demands so that, up to the present time, welding has been excluded for members which are heavily stressed, especially on locomotives. On the other hand, numerous opportunities are afforded for its use on carriages, especially since to-day steel is being used more and more in place of wood. Figs. 8 and 9 * show an interesting type of welded construction in this field, namely, a welded bogie of a main line carriage and a completely welded goods wagon of large capacity. In recent years, the State Railways have gone over more and more to the use of welding in carriage construction, and also in the construction of locomotives.

In *Steam Boiler Construction*, fusion welding is still represented to a much less extent than would be thought from the expectations which are raised here. The factors which oppose it, and which make it more and more difficult, are that the safety of human life depends to a large extent on the quality of the welded work, and that this quality at the present time may only be determined to a very limited extent after the work has been carried out. At the same time, even in steam boiler construction, the welding on of pipe branches, ends, and the welding in of pipes, the welding of water drums, &c., has been introduced.

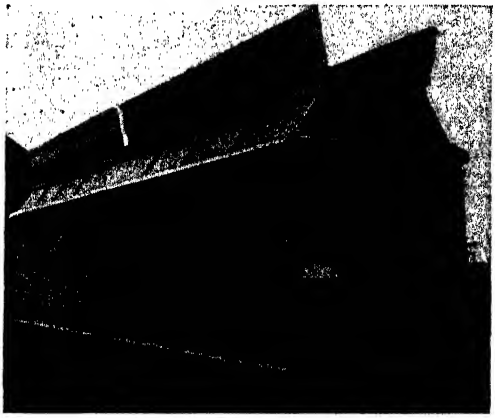


Fig. 9.—Completely welded large capacity goods wagon

The welding together of boiler ends has been carried out by some firms with the aid of water gas welding, and has acquired considerable importance in the manufacture of high quality drums, for example. The application of fusion welding, on the other hand, was first carried out extensively abroad, and only in this country after the straps, which were recommended by Höhn, promised increased safety. Instead of longitudinal straps which should always be avoided, since they only serve to cover the main seam and prevent

* The diagrams have been placed at our disposal by the Wumag und Waggonfabrik, Uerdingen.

examination of it, and since they subject it to danger because of increased stresses due to the contraction of a large number of fillet seams, Höhn uses transverse straps which remove the load from the main seam by the introduction of initial stresses, which are set up during the welding on of the strap and further limit any fracture which may be set up.* A design of this kind is shown in fig. 10. The extent to which the welding of steam boilers is allowed in Germany is governed by the " Werkstoff und Bauvorschriften für Land- und Schiffsdampfkessel (Specification for material and construction for steam boilers on land and in ships) as well as by the " Bestimmungen über Anlegung und Betrieb der Dampfkessel". (Regulations concerning the installation and operation of steam boilers) under section " Schweissung und Bearbeitung im Feuer, IIIA, Allgemeines IIIB, Bewertung von Schweissnähten (Welding and work, IIIA, General IIIB, Assessing the quality of weld seams). Regulations for welding are also

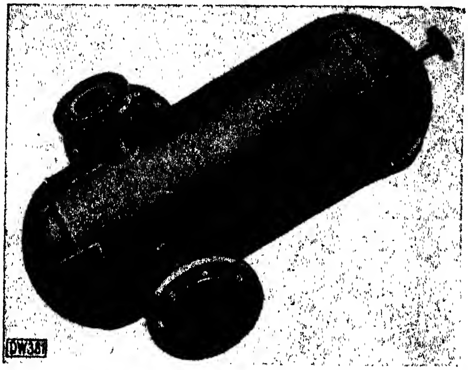


Fig. 10.—Water separator fitted with Höhn straps for a pressure of 30 atm. (450 lb./in.²) and 750° F (400° C.)

Fig. 11.—Francis turbine impeller

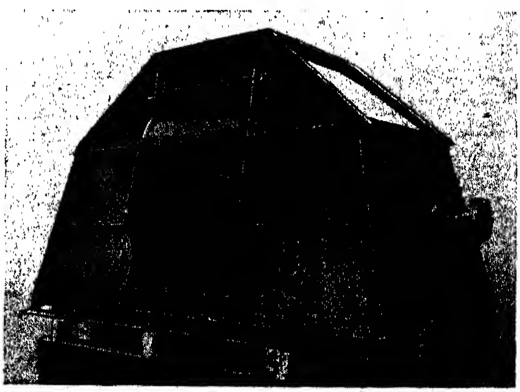


Fig. 12.—Casing for a chimney fan

* Höhn, " Strap Welding in Boiler Construction ", *Schmelzschweissung*, Vol. 8 (1929), p. 69.

given in "Die Richtlinien für die Anforderungen an den Bau von Hochleistungskessel" (Regulations relating to the manufacturing requirements for heavy duty boilers).

The most numerous and the most varied opportunities of applying welding are, of course, afforded in *General Machine Construction.* The following examples may be mentioned. Jigs, bearing blocks, drums for ropes, housings, wheels, &c. To give examples for all these cases would be too much, and hence only figs. 11 and 12 have been included.

The *Replacement of Cast Iron Constructions* by welded constructions in machine construction, in electrical work, and in the manufacture of machine tools, has been discussed in detail, as a very important field.* There is, indeed, no section in the manufacture of new articles in which greater savings in weight and material cost can be achieved than in this. Since rolled steel is much superior to cast iron in respect of its strength and stiffness, the stressed sections may be kept much smaller with rolled steel than with cast iron, in spite of the alternating stresses which arise in machine construction. It should be mentioned that with cast iron the thickness of material, for reasons of casting technique, has to be made greater than that necessitated by the stresses to which the members are subjected. In this way, reductions of section up to 40 per cent may be achieved with welded steel constructions. If it is further borne in mind that the cost of the weight of steel used, as compared with the finished article, is about 1–3, it is possible, by replacing cast iron constructions by welded steel constructions, to achieve a saving of 40 to 60 per cent. The manufacturing costs of the steel construction are approximately equal to the machining costs of castings.

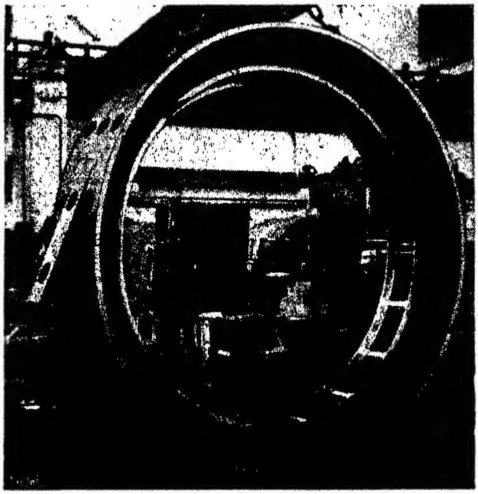


Fig. 13.—Large alternator casing

* "New Methods for the Construction of Machines", *Schmelzschweissung,* Vol. 7 (1928), pp. 7 and 27.

The *Electrical Industry* has gone over almost completely to the use of steel in place of cast iron for the manufacture of dynamo and transformer housings as well as for their baseplates, and fig. 13 shows an example of this.

In machine-tool construction the cast members of various machines have recently been replaced by steel designs which, because of their greater stiffness, have the additional advantage of increasing the life of the tool. A design for machine tool construction is shown in fig. 14.

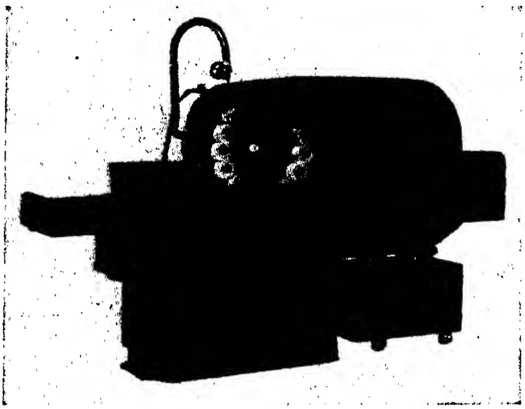


Fig. 14.—Welded grinding machine

Welding has acquired considerable importance in *Crane Construction* which has gradually gone over almost completely to this type of construction.*

The welding of *Steel Buildings*, building roofs, and bridges may be regarded as very promising for the future. If one previously had scruples in departing from the proved rivet for highly stressed constructions of this type, the path has now been cleared by the Vorschriften für geschweisste Stahlbauten (Specifications for Welded Steel Buildings) D.I.N. 4100, which contain accurate data relating to materials, welding processes, calculations, structural design, and acceptance for buildings and bridges.

The very important advantages of welding, as compared with riveting, in this field depend on the savings in material, weight and work. The first is obtained by dispensing with the connecting

* Wundram, " Electrically Welded Cranes ", *Schweisstechnische Rundschau des Technisches Zentralblatts*, Vol. 3, 1931, p. 3.

pieces such as gusset plates, which are necessary in riveting, and, in addition, the sections may be made lighter since they are no longer weakened by rivet holes. Moreover, it is unnecessary to make a flanged girder or a column as strong for its whole length as is necessitated by the maximum stress which may occur at one point. We have become independent of rolled sections and by welding on plates to the web plate we may give it any shape we may desire corresponding to the bending moment curve. The reduction in dead weight, which is achieved by the savings in weight which we have mentioned, leads in turn to lighter constructions. In this way,

Fig. 15.—Welded crane rail construction

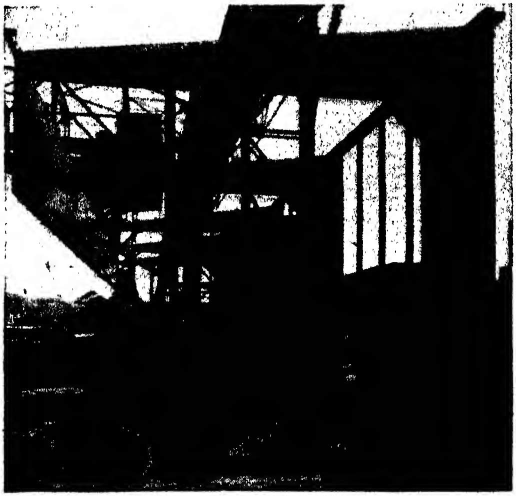


Fig. 16.—Welded shed construction

with welded designs, savings in weight have been achieved which amount to 30 per cent of the riveted construction. The savings in work are to be found in dispensing with marking off, drilling and drifting the rivet holes, and in the fact that for carrying out welding, only one workman is, as a rule, necessary, whereas in riveting, a riveting gang consisting of two to three men is required. The assembly of the parts is usually simpler in welding and may be facilitated still further by the use of suitable jigs such as has been suggested, for example, by Schmuckler.* In conclusion, a few diagrams may indicate the advance which may be made in steel construction. Fig. 15 shows the simplicity of the joints, fig. 16

* Schmuckler, "Welding Technology in Steel Construction", *Elektroschweissung*, Vol. 1 (1930), p. 236.

the construction of a shed, in which the excellent way in which the corners have been designed, should be mentioned, and fig. 17 shows the first completely welded railway bridge of the German State Railways.

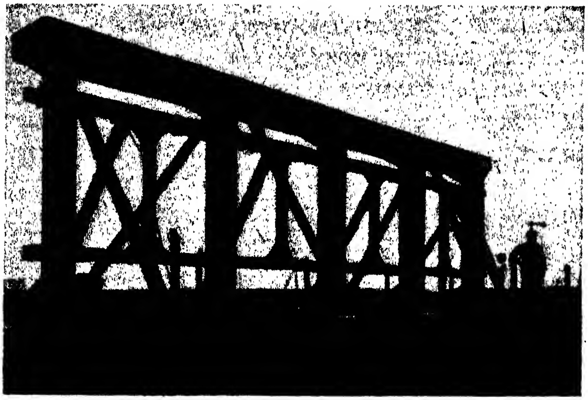


Fig. 17.—The first completely welded railway bridge of the German State Railway

Finally, we should mention that welding has proved extraordinarily useful in the *Strengthening of Riveted Steel Constructions*, especially of bridges, and that welding makes it possible to carry out work without interrupting the service.

CHAPTER III

The Quality and Economics of Welding Processes

Fusion Welding

Quality of Fusion Welding

In order to determine to what stresses welded seams may be subjected, comprehensive tests on workshop specimens of all kinds were carried out in the early days of the application of welding. Reference is here made to the fundamental tests which were carried out years ago by Höhn, Bock, Neese, Gollwitzer of the Forschungsgemeinschaft für Schmelzschweissung (Research Association for Fusion Welding, Hamburg).* After these tests had proved that successful welding could at last give the same, and frequently a greater, strength than riveting, one went over very rapidly to the use of welding in almost all fields.

There is no doubt that the quality of the weld seam in fusion welding is dependent to a very great extent on the reliability and skill of the welder. At the same time, the quality of the weld is not only influenced by these factors, but also by a series of other circumstances such as the properties of the welding wire and the peculiarities of the various processes, the position of the weld seam, in the construction, &c. Consequently, it is necessary to deal with these matters more closely because they are of great importance in the design and calculation of a construction.

The " Vorschriften für geschweisste Stahlbauten " D.I.N. 4100 (Beuth Verlag), (Specifications for Welded Steel Buildings) drawn up by the Fachauschuss für Schweisstechnik, of the V.D.I., by the Ausschuss für einheitliche technische Baupolizeibestimmungen

* Bock, *Maschinenbau*, Vol. 4 (1925), p. 989.
Neese, *Stahl und Eisen*, Vol. 42 (1922), p. 1001, 1192.
Neese, *Zeitschrift des Vereines deutscher Ingenieure*, Vol. 68 (1924), p. 1125.

(E.T.B.) and by the German State Railway Company give information dealing with the *Calculation of Welded Joints*. The Regulations for Calculations may also be used for other work. For parts which are not stressed so highly, the permissible stresses may be chosen somewhat greater.

Examples for the calculation of V- and X-seams, butt joints with fillet seams, lateral fillet seams, longitudinal fillet seams and lapped joints, have been made by Haas.* They are shown here on pp. 213 to 215 as figs. 1 to 19.

Calculation guarantees adequate safety if the process and the material are correctly chosen, if reliable welders are employed, and if welding can be carried out under simple conditions.

The following remarks should indicate what effect these primary requirements ought to have on quality.

As far as the choice of filler material is concerned, it may be assumed that the conditions for the supply of welding wire which were mentioned on pp. 129 and 130 prescribe what values should be obtained with various welding wires, using normal constructional steel (St. 34 and St. 35), from a welder having average skill. In addition, they indicate that the choice of the process is of some importance, at least as far as ductility is concerned, since in general with arc welding the same quality cannot be achieved, in respect of this property, as can be obtained with gas welding.

Tests have shown the way in which the process, the quality of the base material and of the welding wire exercise their effects. In the Technical Welding Research Department, a large series of tests was carried out at the beginning of the year 1931, on plates of approximately $\frac{3}{16}$, $\frac{3}{8}$, and $\frac{5}{8}$ in.† in order to compare forward and backward welding in the gas welding process.

It was shown that in respect of quality, for horizontal single run junction welding, on plate thicknesses of $\frac{3}{16}$ to $\frac{5}{8}$ in., backward welding is to be preferred to forward welding because of the savings in gas, time and filler material, especially when the seams could not be improved by hammering.

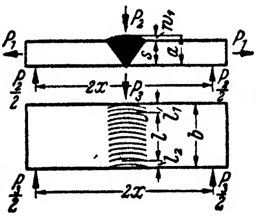
As has been known for a long time, the position of the weld seam in the construction has considerable influence on the quality of the welding. Welding in an uncomfortable position, in a vertical direction or even overhead, must result in the welder's work being of

* Haas, "Selected Examples in Welded Construction", Vol. 2, Machine Construction, pp. 1 to 3. (Berlin, 1931, V.D.I. Verlag.)

† Bardtke and Matting, "Comparative Investigation on Forward and Backward Welding", *Autogene Metallbearbeitung*, Vol. 24 (1931), pp. 159 and 175.

PERMISSIBLE STRESS ON WELD SEAMS IN MACHINE CONSTRUCTION

Type of Loading	Loading Class	Permissible Stress in Tons/In.[2]
Tension	I II III	5·7 3·8 1·6
Compression ..	I II	5·7 3·8
Bending	I II III	5·7 3·8 1·6
Shear	I II III	4·75 3·20 1·30



V-Seam

$$a = s + w_1 \leq 2s.$$

$$l = b - (l_1 + l_2). \quad l_1 = l_2 = \tfrac{5}{16} \text{ in.}$$

Tension: $P_1 = alk_T$.

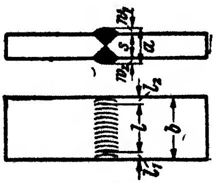
Bending horizontal edge in both directions:

$$M_B = \frac{P_2 x}{2} = \frac{la^2}{6} k_B.$$

Bending vertical edge in both directions:

$$M_B = \frac{P_3 x}{2} = \frac{al^2}{6} k_B.$$

On machined pieces, $a = s$ and $l = b$.



X-Seam

$$a = s + w_1 + w_2 \leq 1{\cdot}3s.$$

$$l_1 = l_2 = \tfrac{5}{16} \text{ in.}$$

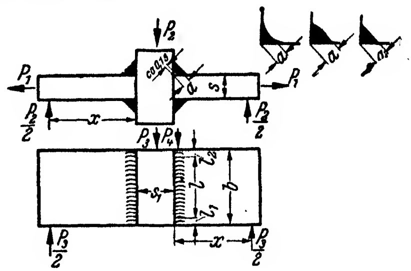
$$l = b - (l_1 + l_2).$$

Tension and bending formulæ are the same as for the V-seam.

The formulæ given and the permissible stresses only apply to arc welded seams made with bare electrodes, on a straight steel, with a carbon content of not more than 0·25 per cent. The use of a direct-current welding machine has also been presumed.

Figs. 1–4. Dimensions of V- and X-Seams

Cruciform Joint



Tension:

$$P_1 = \sqrt{2}\,(a - 0{\cdot}1s)lk_T.$$
$$l = b - (l_1 + l_2).$$

For pieces machined on the sides,

$$l = b.$$

If the strength of the joint is the same as that of the tensile piece (steel 37, $k_T = 22$ tons/in.^{2}), $a = 0{\cdot}85s$.

Bending horizontal edge:

$$M_B = \frac{P_2 x}{2} = 2l(a - 0{\cdot}1s)\left(\frac{s}{2} + 0{\cdot}35a\right)k_T.$$

Rough rule: $M_B = \dfrac{P_2 x}{2} = 1{\cdot}1\ lask_T.$

If the strength of the joint is the same as that of the bend specimen (St. 37, $k_T = 22$ tons/in.^{2}), $a = 0{\cdot}3s$.

Bending vertical edge:

$$M_B = \frac{P_3 x}{2} = 0{\cdot}23(a - 0{\cdot}1s)l^2 k_T.$$

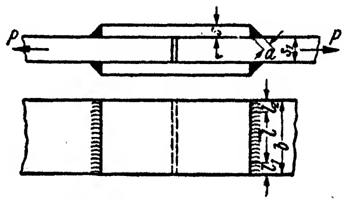
If the strength of the joint is the same as that of the bend specimen (St. 37, $k_T = 22$ tons/in.^{2}), $a = 0{\cdot}75s\dfrac{b^2}{(b - 1{\cdot}6)^2} + 0{\cdot}1s \approx s.$

Shear:

$$P_4 = 2(a - 0{\cdot}1s)lk_S\sqrt{1 - \frac{\sigma_{BI}}{2\sigma_N + 39}};$$
$$\sigma_{BI} = \frac{P_4}{sb};\quad \sigma_N = \frac{P_4}{2al}.$$

Rough rule: $P_4 \approx 1{\cdot}5\ alk_T.$

Frontal Fillet Seam

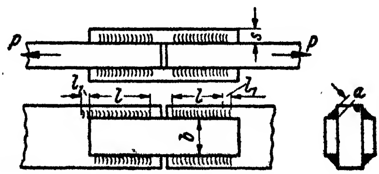


Tension:

$$P = \sqrt{2}(a - 0{\cdot}1\,s)lk_T.$$

If the tensile piece (St. 37) and the weld ($k_T = 22$ tons/in.^{2}) are to have the same strength, we must have in the design of a normal seam $s \approx s_1$, so that $a \approx 0{\cdot}7s_1$.

Side Fillet Seams



l_1 = crater = $\frac{5}{16}$ in.

Shear:

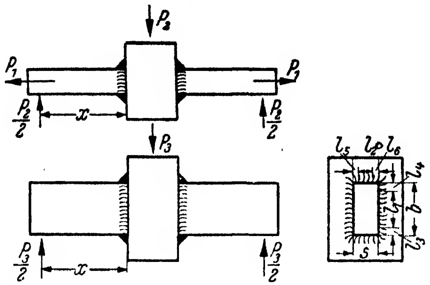
$$P = 4(a - 0{\cdot}1\,s)lk_S\sqrt{1 - \frac{\sigma_{BI}}{2\sigma_N + 39}};$$
$$\sigma_{BI} = \frac{P}{sb};\quad \sigma_N = \frac{P}{4al}.$$

Rough rule: $P = 3alk_T$.

If the straps and the weld are to have the same strength (St. 37, $k_S = 19{\cdot}7$ tons/in.^{2}), in normal seams $l \approx b$

Figs. 5–12. Dimensions of cruciform joint with frontal and side fillet seams

Cruciform Joint—Welded on all Sides



$l_3 = l_4 = l_5 = l_6 = \frac{5}{16}$ in.

$l_1 = b - l_3 - l_4.$

$l_2 = s - l_5 - l_6.$

Tension:

$$P_1 = 2(a - 0{\cdot}1s)(l_1 + l_2)k_T.$$

Bending horizontal edge:

$$M_B = \frac{P_2 x}{2} = (a - 0{\cdot}1s).$$

$$[l_1(s + 0{\cdot}7a) + 0{\cdot}23s^2]k_T.$$

Rough rule:

$$M_B \approx a(bs + 0{\cdot}2s^2)k_T.$$

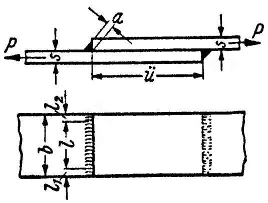
Bending vertical edge:

$$M_B = \frac{P_3 x}{2} = (a - 0{\cdot}1s).$$

$$[l_2(b + 0{\cdot}7a) + 0{\cdot}23b^2]k_T.$$

Rough rule: $M_B \approx a(bs + 0{\cdot}2b^2)k_T.$

Lap Joint



$l = b - l_1 - l_2.$

$l_1 = l_2 = \frac{5}{16}$ in.

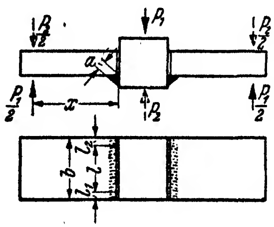
Tension:

$$P = \frac{2(a - 0{\cdot}1s)lk_T}{1 + \left(\frac{s}{\ddot{u} + 3a}\right)^2}.$$

Rough rule for $\ddot{u} \geqq 4s$: $P = 1{\cdot}8\,alk_T.$

If the plate (St. 37) and the weld ($k_T = 22$ tons/in.^{2}) have the same strength, $a \approx 0{\cdot}65s$ for $\ddot{u} \geqq 4s$.

Cruciform Joint Welded on One Side



Bending (seam on tension side; surface of joint machined):

$$M_B = \frac{P_1 x}{2}$$

$$= \left[(a - 0{\cdot}1s)\left(\frac{s}{2} + 0{\cdot}35a\right) + \frac{s^2}{12}\right]lk_T.$$

Rough rule: $M_B = 0{\cdot}83alsk_T.$

Bending (seam on the tension side; surface of joint unmachined).

Rough rule: $M_B = 0{\cdot}3alsk_T.$

Bending (seam on the compression side):

$$\frac{P_1 x}{2} = \frac{l(a - 0{\cdot}1s)^2}{6}k_T.$$

Figs. 13–19. Dimensions of a cruciform joint weld on all sides and on one side; also of a lapped side

poor quality. In order to obtain some clear idea of how great this influence was, tests were drawn up for this matter by the Welding Technical Research Department at Wittenberge. Electric arc welding was chosen as the process, and, in addition, two series of tests with ⅜ in. thick plates were carried out in order to obtain simultaneous comparative values between bare and covered electrodes, and with direct current and alternating current.

With direct current and bare electrodes, angles of bend of 97° were obtained with a horizontal V-seam, 82° with a vertical V-seam, and 81° with an overhead welded seam. The corresponding values with alternating current and covered electrodes were 93° with a horizontal V-seam, 115° with a vertical V-seam, and 97° with a V-seam welded overhead. It will therefore be seen that, in both cases, by using a good welding material, values may be obtained by a skilled welder which lie above those laid down by the conditions of supply for welding wires. It was further confirmed that better ductility figures could be obtained with covered electrodes.

With reference to the tensile tests the result was different. In this respect, the following values were obtained for the tensile strength using direct current and bare electrodes and refer to the strength of the unwelded plate: 100 per cent for a horizontal V-seam, 94 per cent for a vertical V-seam, and 90 per cent for a V-seam welded overhead. With alternating current and covered electrodes the values were: 90 per cent for a horizontal V-seam, 90 per cent for a vertical V-seam, and 66 per cent for a V-seam welded overhead. The individual values of the range of tests with alternating current showed at the same time a greater variation than the series of tests with direct current. This may be due to the fact that the welder who was skilled in the use of bare electrodes and carried out excellent work with them did not possess as much experience with covered electrodes. Later comparative tests, carried out by a special welder with covered electrodes belonging to a special firm, however, did not give very much better figures.

In any case, the conclusion may be drawn from these tests that there exists no reason to depart from the use of bare electrodes with steel of boiler plate quality (St. 37), as far as the strength and tightness of the joint are concerned. For overhead welding, the light flowing covered electrode must be classed as definitely unsuitable. For welding in the horizontal position, it requires a welder who is well versed in its use to meet the slightest difficulty which would

impair the quality of the welding because the slag is difficult to drive out, whereas with seams which are slightly inclined or vertical it easily flows away, so that with seams of this type better figures may be obtained.

The breaking tests were extended further to longitudinal fillet seams. With direct current for seams welded with bare electrodes, the shear strength for both horizontal and vertical welded seams lay well above that specified, which, according to regulation, should amount to 15·2 tons/in.^{2}. With alternating current and covered electrodes only the vertically welded specimens were satisfactory. The horizontally welded specimens showed reduced penetration and slag aggregation at the root of the seam.

Finally, breaking tests were carried out on lateral fillet seams. In this case, the horizontally welded specimens, using direct current and bare electrodes, were excellent, and they almost all broke in the parent material. The overhead seams, which were welded under identical conditions, also showed that they were fit for service. The vertical seams, on the other hand, showed that, on the average, they satisfied the requirements, and in this respect it is worthy of note that the seams which were welded from the top to the bottom were better than those welded in the opposite direction. With alternating current and covered electrodes the figures in all cases were below requirements. They were extraordinarily low in the seams welded in the horizontal direction.

These results, therefore, show that seams may be welded overhead without further consideration. In the calculation of these welded joints, however, it must be borne in mind that their strength is less than seams welded in the horizontal or vertical position, and this is of greater importance if the work is not carried out by specially skilled welders.

It was fundamentally proved by these tests that a sound weld seam always guarantees greater strength than a riveted seam in which it is customary to reckon on a strength of 60 to 65 per cent of the plate strength.

As long as welded constructions were being dealt with in which only normal tensile, compressive, or bending stresses occurred, one was satisfied with these results of adequate strength, as compared with those in which the weld metal possessed a high degree of deformation in the cold condition. The view has frequently been expressed regarding low ductility, especially with arc welding, that this was less important than the strength, since with a seam having

sufficient strength, the elongation was taken up by the adjacent base material itself.

Since one has gone over, in recent years, to the welding of constructions, especially boilers, which are subjected to rapid alternating or impact stresses, under which the weld seam made by former methods and previous practice is very brittle, one has to be careful to satisfy these requirements as well.

In addition to raising the low ductility, the notch impact value of the weld metal which was previously almost non-existent, had to be increased to a value which would satisfy all requirements. It has always been possible with fusion-gas welding, in which a normal welded joint always possesses an impact value of 90 to 140 ft. lb./in.^{2} inside the weld seam, to obtain a satisfactory impact value and elongation by subsequent annealing. This has the effect of refining the coarse structure which is less resistant to impact. Since it is impossible, however, to anneal unwieldy parts complete in a suitable furnace, the subsequent annealing was usually carried out by going over the finished weld seam with the flame of the welding torch. This may result in the danger that overheating of the weld material may take place and greater stresses may be set up in the article. From tests carried out by Buchholz * it has been shown that, on V-shaped welds, it was sufficient to weld on the underside, and on X-shaped welds it was sufficient to apply a thin top run on one side of the plate in order to obtain an annealing temperature, which resulted in an increase of the notch impact value to 550 ft. lb./in.^{2}. For both methods of welding, it is preferable to use the backward welding process to the forward welding process, since, due to the higher welding speed which may be obtained with the former, satisfactory heat treatment is obtained, whereas the slower forward welding leads more easily to additional overheating of the weld metal.

For weld seams which are made by arc welding, nothing can be achieved by this method. It is true that with this process the putting down of the top run results in a normalizing of the lower runs, in so far as the structure is refined by the heat treatment, but pores which are unavoidable in welding with bare electrodes, remain behind, or slag which usually occurs with the majority of covered electrodes is left instead. The notch impact value of an electrically welded seam is essentially lower than one welded with acetylene. With bare electrodes it amounts to scarcely more than 70 ft. lb./in.^{2}.

* Buchholz, "A suitable autogenous welding process for boiler and container construction", *Die Wärme*. 55 *Jahrgang* (1932), No. 22, p. 365.

Lightly covered electrodes behave similarly. The annealing of a seam of this kind generally results in an even lower value, generally about 35 ft. lb./in.^{2}, which is only half the above figure, so that one is scarcely in a position to speak of notch impact value at all.

The obtaining of a notch impact value of 460–550 ft. lb./in.^{2}, as is required for constructions which are subjected to rapidly alternating or impact loads, is entirely a question of electrodes. As was mentioned in the Section on "The Welding of Steel" in the first part of this book, it is only recently that there has been any success in the manufacture of electrodes which fulfilled all requirements in respect of notch impact value. Such electrodes are the heavy coated electrodes. With these electrodes, success has been achieved in that the structure of the weld zone, as well as the transition zone of the seam, is absolutely identical with the base material. Their use is, therefore, always to be considered where high notch impact values are required.

ECONOMICS OF FUSION WELDING

The total cost of a weld seam consists of:

Wage charges.
Costs of filler material.
Power charges (gas or electric current).
Supplementary charges (plant charges, interest, depreciation, transport charges, &c.).

We will first discuss how the costs of welding compare with the costs of riveting, since this is of primary importance for the application of welding.

Instead of the costs of filler material for the welded seam, we have for the riveted seam the material costs of the rivets and the overlapping and cover plates or the necessary gusset plates or angle irons, which are required for joints of plates which are bolted to one another or which abut against one another at a corner.

Strelow has made detailed researches into the cost of a welded seam as compared with a riveted seam.* The result may be seen in figs. 20 and 21. Values were obtained from electric welding in shipbuilding and consequently they cannot unconditionally be adopted for other types of application. However, they form a good basis for calculation, since the special conditions operating for the

* Strelow, "Maschinenbau", (6) (1927), pp. 540, 610, 664.

individual fields of application primarily affect the wages costs, whereas material charges, power charges and supplementary charges on the other hand will in general only differ from one another to a slight extent. Additional charges will be added to the wages charges in welding, for example, in boiler construction where high strength and tightness is required from the weld seams or where welding has to be carried out under very difficult conditions. On the other hand, the wage charges will be lower when welding can be carried out at the welding bench or at least in a comfortable position.

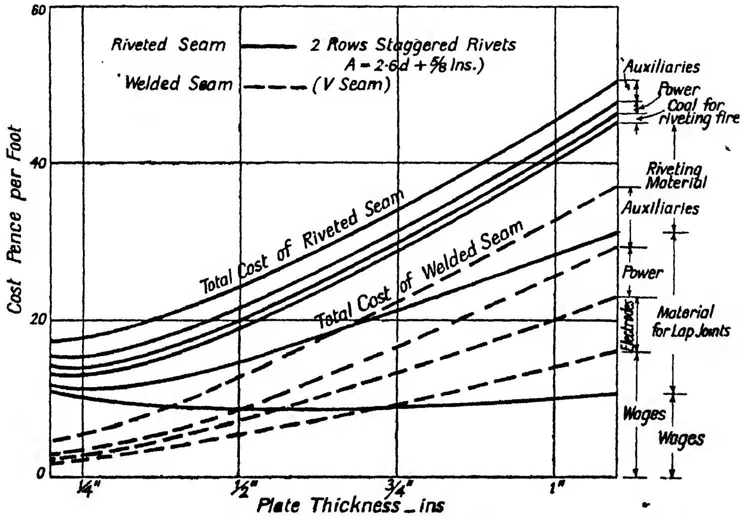


Fig. 20.—Summary of the costs of a riveted seam (2 row staggered rivets) and a welded seam

In any case, the curves given in figs. 20 and 21 show that the total cost of a riveted seam is considerably higher than that of a welded seam of corresponding strength.

The saving in material is the decisive factor in welding, and this can be made more effective the more regard is paid in design to the peculiarities of welding. On the other hand, the curves in fig. 20 show that the wages charge in riveting is only higher than that in welding for plate thicknesses up to about ¾ in. and afterwards is less than the welding charge. This may be explained as follows: In welding the only items with which we have to deal are the marking-off of the plates, cutting, tacking and welding. In riveting, on the other hand, we have to deal with the marking-off of the plates, drilling, countersinking and drifting of the rivet holes and the rivet-

ing, and in certain circumstances also with the bevelling of the edges of the plate and caulking of the seams. In addition, riveting requires three sets of equipment for the operations, namely, rivet heating, holding-up and hammering equipment, as compared with one set of equipment for welding, and this necessitates the co-operation of several men as compared with one welder.

This extra work in riveting is offset, however, on thick plates, since, in the welding of these, a longer time is necessary for the

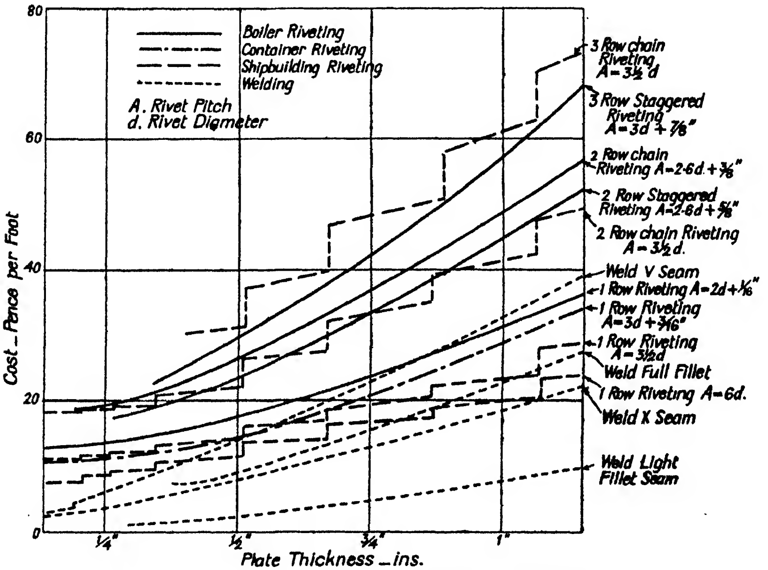


Fig. 21.—Total costs of various types of riveted and welded seams

filling-up of the weld groove which increases in depth and width with the plate thicknesses.

Strelow has also determined corresponding figures for fusion-gas welding. Since the introduction of backward welding, which has modified the conditions considerably in favour of this kind of welding, they can no longer be applied.

Even if, as we have shown, the savings to be realized by the replacement of a riveted construction by a welded construction are considerable, the saving which can be made by applying welding to many other fields is very much higher. As an example we will compare the costs of a construction made by cast iron by the casting process and one made by welding from rolled steel with one another.

Under alternating stresses, the permissible compressive stresses

for steel and cast iron are not widely different. For tensile stresses, however, the permissible stresses amount to 4·15 tons/in.^{2} for steel, but only 0·75 tons/in.^{2} for cast iron. Hence, neglecting the stiffness, 17 per cent of the section of cast iron is required for steel. If it is more a question of stiffness than of strength, the section may only be reduced to 40 per cent. Since, however, the cost ratio per unit weight of steel and cast iron is 1 : 3, the material charges for the steel construction are only 40 by $\frac{1}{3}$ = about 13 per cent of the cast iron construction.

In addition, we have to add the savings in wages. The wages for welding correspond approximately to the wages which would have to be paid for the machining of the finished casting, and which are not incurred in the welded construction. Also the wages which are required for moulding and casting are saved.

Finally, we have a saving of the cost of making the pattern which may prove very expensive, especially for single castings, but even in mass production work they have to be taken into account because of their depreciation and storage charges. Hence the replacement of cast iron constructions by welded steel constructions is one of the most economical applications of welding.

A similar economic application of welding is to be found in pipe line construction to replace screwing. A few figures will have to suffice. A simple pipe joint utilizing a screwed sleeve costs about 29·5 pence for a pipe of 3 in. diameter for wages, material and manufacturing charges. A welded joint to replace it costs only 6 pence. The savings on complicated joints are even greater. The cost for a bend on such a pipe amounts to 57 pence for screwing and 8·5 pence for welding. For a T-piece the figures are 67 pence and 9 pence respectively.

Briefly therefore we can say that, to realize a saving by welding, one has to bear in mind the peculiarities of welding. The way in which a skilled designer may influence the cost may be illustrated by an example.

A continuous fillet seam has the same strength as an interrupted one which is half as long but twice as thick. Since the volume of the seam increases with the square of its depth, the costs of a discontinuous seam are multiplied by four by doubling the height, whereas they are only doubled by increasing the length. For economic constructions, therefore, the continuous long fillet seam is preferable to the interrupted seam of the same strength which should only be chosen when there are other reasons in its favour.

A careful design should also take into account the reduction in the number of movements by adopting the correct order of welding, and in this way contribute to a cheapening of the work.

The choice of the welding process, the filler material and the position of the weld is of much greater importance for the economy of welding than for attaining high quality figures. In addition, we have to deal with the difference in cost of power (generated gas, dissolved gas, electric current), and finally with the important in-

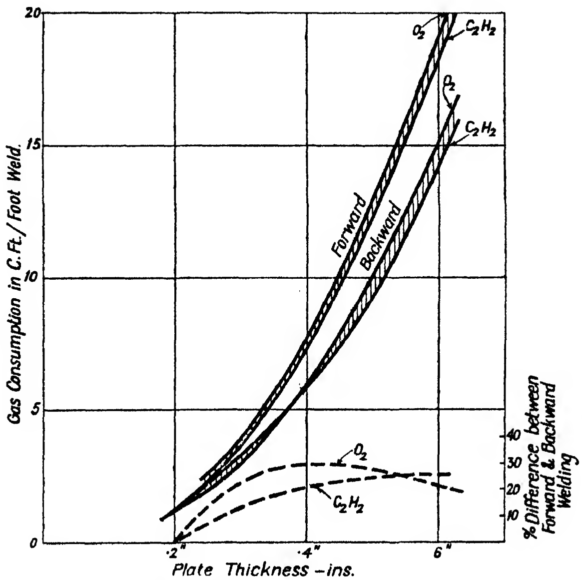


Fig. 22.—Gas consumption in cubic feet for 1 foot of weld for forward and backward welding (——)

Difference in gas consumption between forward and backward welding (— — — —)

fluences which supplementary charges exercise, depending on the local conditions. The varying skill of the welder, which we have not taken into account, should also be remembered.

Forward gas welding, backward gas welding and arc welding will now be compared. The values for gas welding were obtained from the series of tests which we have already mentioned, made by the Welding Technical Research Department at Wittenberge, and the values for arc welding are taken from the determinations of Strelow.

Since wage rates are different in various places, the conclusions are not based on wage charges, but on the welding time. In the

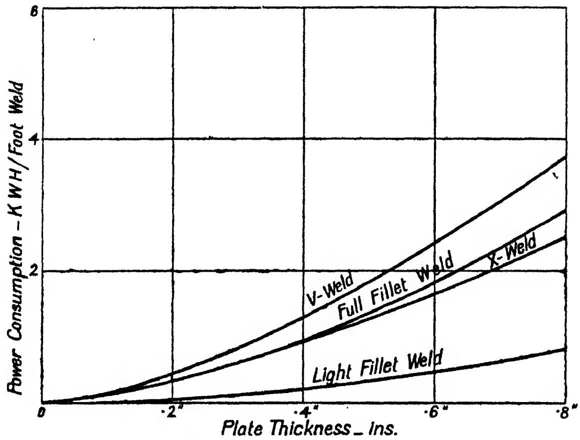


Fig. 23.—Power consumption in kw.h. for 1 ft. of weld

same way the consumption of power and filler material is dealt with, but the costs of these are not included. In this way the costs may easily be determined from case to case.

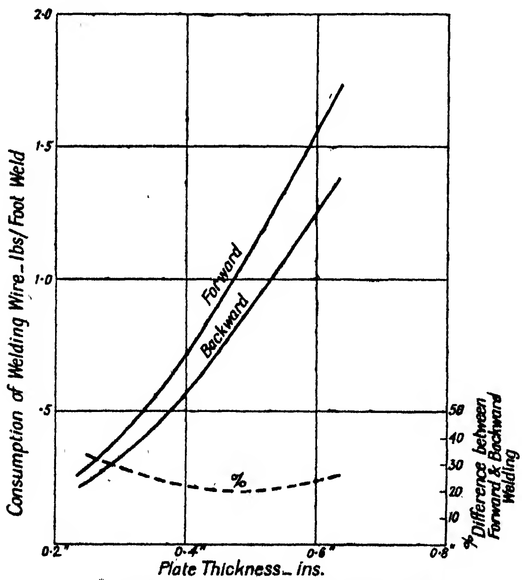


Fig. 24.—Consumption of weld wire in lb./ft. of weld for forward and backward gas welding (———)

Difference in consumption of welding wire in forward and backward welding (— — — —).

Fig. 22 shows the gas consumption in gas welding and fig. 23 shows the current consumption in arc welding. It will be seen that the gas consumption in backward welding is less than in forward welding because of the increased welding speed, although more gas is required in unit time, since work must be carried out with a larger flame. In addition, it will be seen that, if the price for gas and electric current is inserted, the time costs for arc welding are considerably less.

If, on the other hand, the consumption in filler material is com-

pared from the curves given in figs. 24 and 25, it will be seen that the backward welding curves come out better than the forward welding curves, and this is due to the fact that, in the former instance, the welding groove has to be made broader than with the latter. On the other hand, the consumption of filler material is almost the same for backward welding with gas and for arc welding provided a V-shaped seam is used, since the size of the angle of bevel for these two processes has to be made the same.

The *time* required for welding may be obtained from figs. 26 and 27. Fig. 26 shows how backward welding compares in this

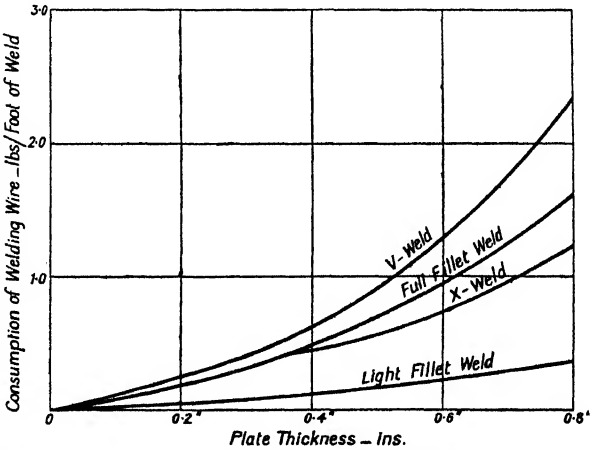


Fig. 25.—Consumption of welding wire in lb./ft. of weld. Arc welding

respect with forward welding. It will be seen that with a plate size of about $\frac{3}{16}$ in. a point is reached where the time required is the same for the two processes. Since the difference in power and filler material consumption almost cancel one another out, the costs of the weld seam for this plate thickness are almost the same. For thinner plates up to $\frac{3}{16}$ in. forward welding is cheaper. For thicker plates up to $\frac{5}{8}$ in., if welding is done in one run, backward welding, on the other hand, is considerably superior. The savings in time for backward welding, as compared with forward welding, amount to:

For $\frac{1}{4}$ in. plates	about 22·5 per cent.
For $\frac{3}{8}$ „ „	about 58·8 „ „
For $\frac{5}{8}$ „ „	about 45·2 „ „

Bearing this in mind, the conditions relating to a comparison between fusion-gas welding as compared with electric welding from the point

of view of cost, have changed fundamentally from the early days. The opinion can no longer be held that arc welding is cheaper in every case. The output with fusion gas backward welding at least approximates to that of arc welding. A comparison of the curves in figs. 26 and 27 give the impression that, for heavy plates, the welding speeds with fusion-gas backward welding are considerably greater than those with arc welding. The figures mentioned, however, cannot be directly compared, since the times obtained with gas welding were done on the welding bench, whereas the times with arc welding were obtained on practical work under unfavourable conditions. In the comparison of direct current welding with bare electrodes and alternating current welding with covered electrodes from the series of tests made in the Welding Technical Research Department, Wittenberge, it was determined that, in arc welding using direct current and bare electrodes, on $\frac{3}{8}$ in. thick plates, 6·5 ft. of seam could be made in the hour, i.e. approximately the same length of seam as in backward gas welding. As was mentioned, the tests were carried out at the welding bench. It may be assumed that the welding times for arc welding will always be less than those for the new gas welding process as long as only one run has to be put down, but that the times of both processes approach one another more closely the greater the thickness of the plate and the greater the number of runs which have to be put down in arc welding, and finally that gas welding will come out slightly more favourable.

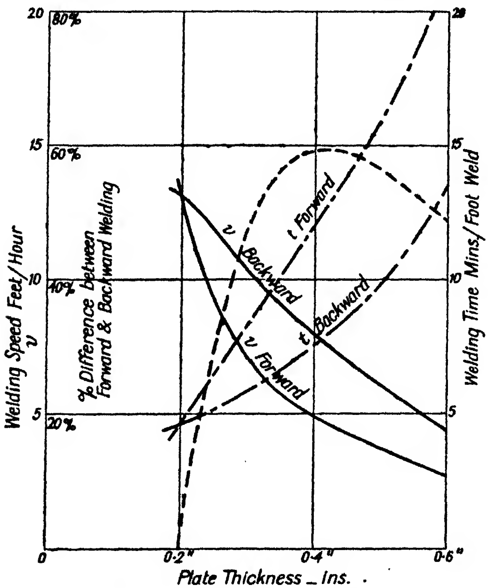


Fig. 26.—Welding speed v (———) and welding time t (– – – –) for forward and backward gas welding, depending on plate thickness.

Difference between forward and backward welding (- - - - -).

In the determination of costs, the costs of the power consumed will introduce modifications. The supplementary charges, which are influenced to a large extent by local conditions, may strongly

influence all determinations, and these will be discussed later. We will now show what variation in the cost of welding is called into play by welding in various positions.

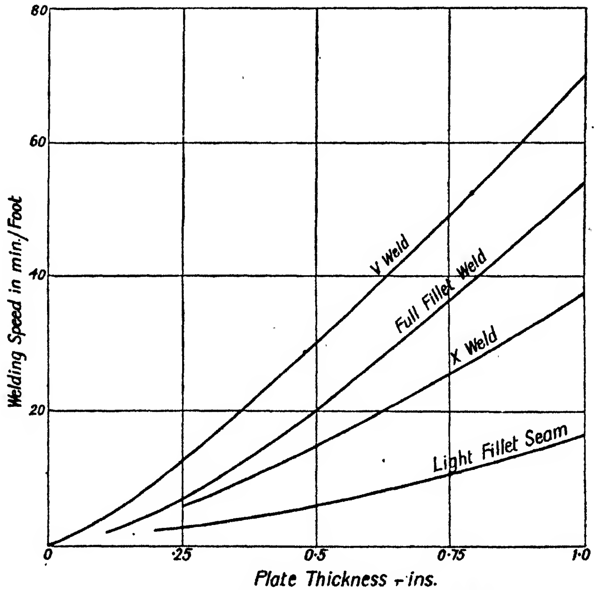


Fig. 27.—Welding speed for 1 ft. weld. Arc welding

N.B.—These results were obtained in 1927; values obtainable to-day are about 5 per cent less than these

The results which were obtained on a series of tests of ⅜ in. plate with arc welding in the horizontal, vertical and overhead positions, and which were mentioned above, are as follows. The output amounted to:

	Direct Current and Bare Electrodes	Alternating Current and Covered Electrodes
Horizontal V seam	6·73 ft./hr.	2·22 ft./h.
Vertical V seam	5·45 „	2·35 „
Overhead V seam	3·97 „	1·36 „
Horizontal Fillet seam	18·3 „	5·87 „
Vertical Fillet seam	15·6 „	6·11 „
Overhead Fillet seam	14·35 „	8·35 „

It should be noted that, in these tests, no importance was attached to the welding speed as primarily the strength values of the specimens were to be determined, that is to say, quality was of primary importance. In spite of this, the results confirm that, for vertical and

especially for overhead seams, considerable increases in the welding time had to be made to that calculated for horizontal seams. In addition, it may be clearly seen that the widely held view that higher welding speeds, as measured by the total quantity of material melted down, could be obtained with covered electrodes because of their fluidity and stabilizing effect on the arc, does not apply. Where a run has to be put down in an inclined position, and where the slag can easily run away, the welding speed for covered electrodes will be greater. Where several runs of welding have to be put down one on top of the other, considerable delays occur, as compared with welding with bare electrodes, due to having to knock off the slag after putting each run down. On horizontal and overhead runs, on the other hand, the welder loses time by using covered electrodes because he has to drive the slag, which is formed from the covering, out of the fused bath.

In conclusion, since the price of covered electrodes is many times greater than the price of bare electrodes, conditions are more unfavourable towards the former, as is shown from a comparison of the costs based on 1 ft. length of seam. From our tests the following figures were determined:

(*Translator's Note.*—Costs have been converted from marks at the old parity, viz. 1 R.M. = 12 pence).

	Direct Current with Bare Electrodes	Alternating Current with Covered Electrodes
Horizontal V seam	9·0*d.*	25·4*d.*
Vertical V seam	10·2*d.*	28·2*d.*
Overhead V seam	13·3*d.*	45·7*d.*
Horizontal Fillet seam	3·3*d.*	10·7*d.*
Vertical Fillet seam	3·5*d.*	10·9*d.*
Overhead Fillet seam	3·7*d.*	7·65*d.*

For bare electrodes a price of 1·6*d.*/lb. has been inserted, and for covered electrodes a price of 11*d.*

The very striking high costs for the overhead V-seam with covered electrodes may be explained by the fact that a very large angle of 120° had to be chosen in order to be able to drive the slag out at the sides, so that the consumption of filler material was very large. On the other hand, in all other cases, even with overhead welding with bare electrodes, an angle of bevel of 60° was sufficient.

It still remains to discuss the effect of supplementary charges. Accurate figures cannot be given here. These costs may differ very widely, depending on the local conditions which have to be con-

sidered in welding; and in certain circumstances they may have a decisive effect on the choice of the process, and this effect may exceed in importance the previous factors which have been discussed.

Some examples will be given in which this factor appears.

If welded joints have to be made on a stretch of railroad track, consideration must be given as to what source of power is the cheapest. The welding converter or transformer is essentially the cheapest to run. Gas from acetylene generators or cylinders is more expensive, because of the high cost of carbide. In ordinary circumstances it is quite uneconomical to take current from the mains with the aid of a resistance. For the aforementioned case, however, this is the one which is the most advantageous provided that current may be obtained over the whole length of railroad track. The resistance is easy to transport; a source of gas is not so easy; a welding converter is very difficult to transport. Hence, in this case, transport charges play a very important part. In addition, the cost of a resistance and also the cost of a generator is small. Since the welding time, however, only amounts to a few minutes, and is interrupted by long pauses, the time during which the supply of current is used is very small. The plant interest and depreciation charges reckoned on the short welding time, therefore, exercise an effect which completely overshadows all other welding charges in favour of the cheapest source of current.

The time during which the current supply is used always plays an important part, and should never be left out of account in calculations. Welding converters are always very much dearer than acetylene generators. The difference in price increases when we are dealing with a large number of welding points, since a converter has to be provided for every point, but only one large generator is necessary. If the converters are not permanently in use, the gas generator, in spite of the higher cost of energy, especially for low welding outputs, may be the cheaper. The converse may just as easily be true if other conditions obtain. If the welding points are situated far apart, generators may require extensive pipelines which make the plant expensive. The use of separate converters is then cheaper. Other differences can also be mentioned which depend on the locality. These may influence calculations in respect of supplementary charges, and may have an effect on the determination of costs. The difficulty of assessing them is also increased by the fact that there is no accounting basis available for welding purposes

such as has been determined for other operations, and which have been published in the form of Refamappen.* For the same reasons, therefore, the previous remarks dealing with the economics of fusion welding should not be interpreted literally by assuming the values which have been given apply in all circumstances. The remarks on the examples given should only serve as a guide as to what should be taken into account in calculations, so that the savings on a welded joint may be as large as possible and not adversely affected by wrong assumptions.

Pressure Welding

(a) Quality of Pressure Welding

In pressure welding the conditions are considerably simpler. Apart from forge welding, we are concerned here with mass production or the repair of simple parts from which simple specimens for fracture and bend tests may easily be taken, so that reference to the entire series of operations is possible. In addition, numerous tests have shown that, in the electric resistance welding process, welded parts generally have the same strength as the base material. Bad welds are rare since the welding process depends only slightly on the reliability and experience of the welder, and the effect of filler material does not arise. The extent of the heating is the only influencing factor.

Upset and Flash Welding.—It may be shown, however, that in the upset and flash welding processes, welded parts have a lower ductility than forge welded ones. Unsuccessful attempts have been made to overcome this drawback by subsequent treatment. The comprehensive tests which were put in hand as early as the year 1924 by the A.E.G. in co-operation with Füchsel, are of fundamental importance when dealing with this matter. These tests, however, showed that the quality which was obtained from the two processes of upset welding and flash welding was different, as was mentioned during the discussion of the processes. Additional tests showed that:

Annealing in the machine had no effect on the breaking strength of the weld.

* Published by Reichsausschuss für Arbeitszeitermittlung, Berlin, Beuth-Verlag. (*Translator's Note.*—These are publications from which process costs and operating times may be assessed.)

Hammering flush in the machine had a harmful effect on the breaking strength of the weld.

Hammering on an anvil at red heat led to serious damage of the weld.

Butt welding on small sections proved to be more satisfactory than on large sections, as far as their breaking strength was concerned.

The cause of failure of butt welding on heavy sections is apparently due to the processes which take place at the centre of the welded article.

The flash welding process is superior to the upset welding process as far as breaking strength is concerned, and is less dependent on the size of the section.

From cold bend tests and impact bend tests it was, therefore, concluded that:

Annealing in the machine had almost no effect on the ductility and the capacity for bending.

By hammering flush in the machine, and especially by hammering on the anvil, with the accompanying annealing in the machine, a weld was very seriously damaged in respect of its ductility, and its ability to resist deformation.

Welds were obtained by means of the flash welding process which were superior to upset welds in respect of capacity for bending and ductility.

Spot and Seam Welding.—Spot and seam welding processes may be contrasted with riveting since they replace it in the joining of thin plates. There are no extensive tests which are known in which the strength has been determined. They are, however, unnecessary. Anyone may convince himself by breakage tests that spot welded plates seldom or never fracture in the weld, but as a rule in the full plate, whereas in riveting, the fracture almost always occurs through the rivet hole. In this respect, therefore, spot welding is very much better than riveting. The results of seam welded plates, however, are not so good, and these may even fracture in the seam due to faulty workmanship.

As has already been emphasized in the Section on "Pressure Welding Processes", these processes are still in the stage of development. Recent machines have given better results, though only on very limited plate thicknesses. Further improvements in the process may be expected.

(*b*) Economics of Pressure Welding

Upset and Flash Welding.—Although electric butt welding is at least as good as forge welding, even if it is not superior to it, in respect of its strength properties, it is very much superior to it in respect of its cost. How great this superiority is depends on the output of the welding machine which is used. The supplying firms give accurate data on the performance of their machines, and this may be taken as being absolutely reliable. The performance

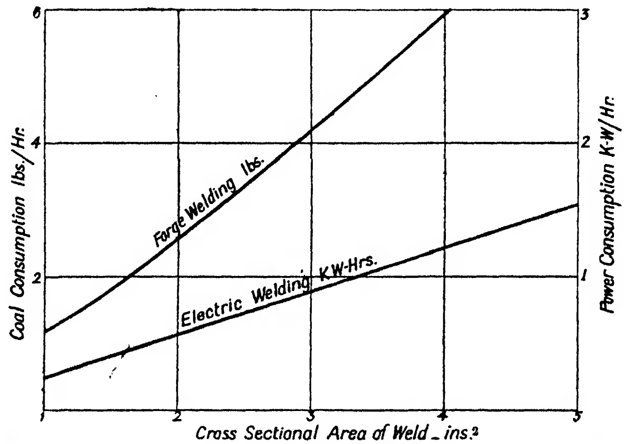


Fig. 28.—Consumption of coal in lb. for forge welding and of electric energy in kw.h. for electric butt welding. (Top curve, forge welding)

may very easily be assessed by tests. Figs. 28–31 give operating curves which come from the A.E.G. They permit of a satisfactory comparison between electric and forge welding, and show that not only is the consumption in coal and heat units very much less for the former, but they also show that the time required for welding is also very much less. Fig. 31 shows how the costs of electric welding compare with those of forge welding.

At the same time, it should be borne in mind that we are dealing here with pure operating costs, and that these do not contain the charges which are called into play by interest, depreciation, and maintenance of the welding machine. If there is not sufficient work available for the machine this may be the deciding factor so that single jobs or the manufacture of a few parts or those which differ considerably in shape may be cheaper with forge welding. Electric welding, therefore, is only economical on mass production.

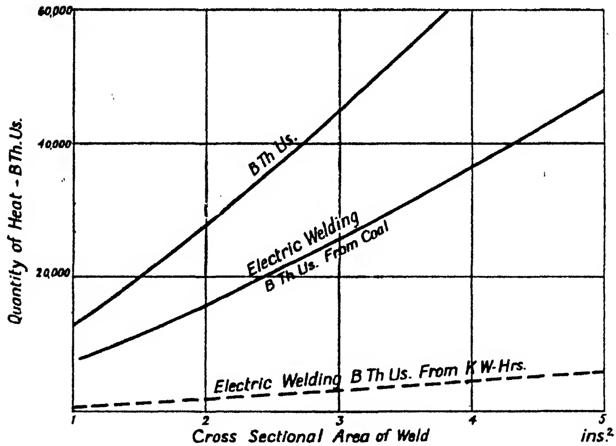


Fig. 29.—Consumption in B.Th.U. for forge welding and electric butt welding. (Top curve, forge welding)

1 lb. furnace coal = 11,000 B.Th.U. 30,000 B.Th.U. per 1 kw.-hr.
1 kw.-hr. = 3400 B.Th.U.

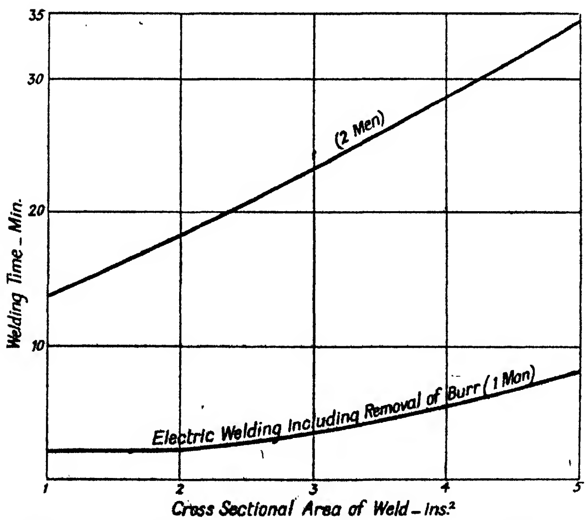


Fig. 30.—Time required on forge welding and electric butt welding (Top curve, forge welding)

It should not be forgotten that a whole series of other advantages is allied to electric welding, and this we have already mentioned in the discussion on "Butt Welding" in an earlier Section.

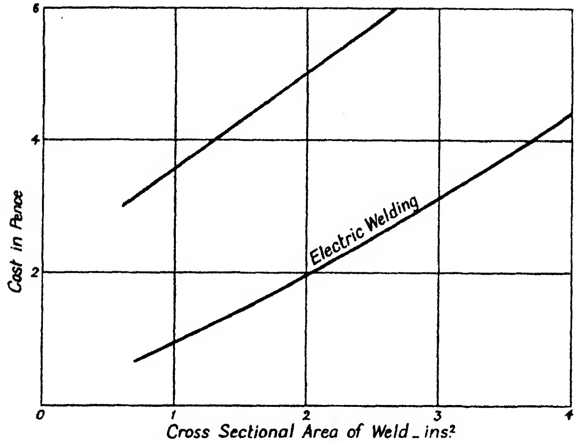


Fig. 31.—Costs of forge welding and electric butt welding
(Top curve, forge welding)

1 working hour = 7·2 pence. 1 lb. furnace coal = 0·22 pence.
1 kw.-hr. = 3·00 pence.

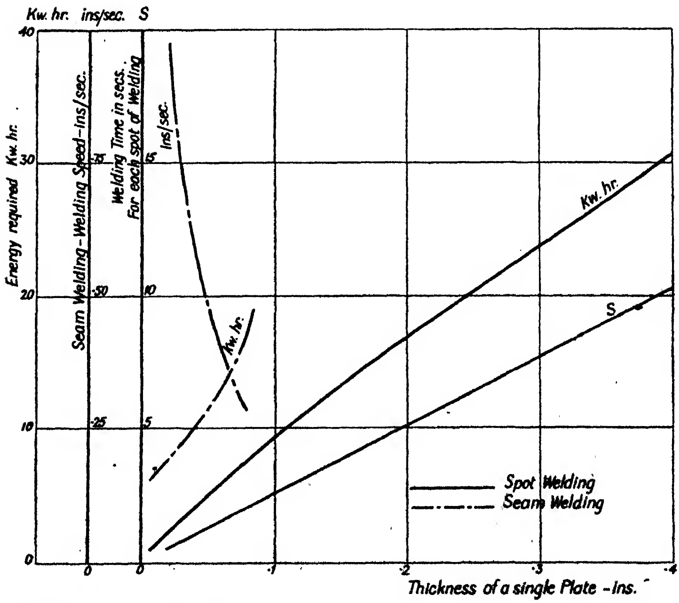


Fig. 32.—Energy consumption and time required for spot and seam welding

Spot and Seam Welding.—Fig. 32 shows the output curves supplied by the A.E.G. for spot and seam welding, and from these the costs may easily be estimated. How advantageous spot welding

is may be seen from some examples which have been put forward by Goldmann in the Special Number "Welding Technology" of the V.D.I. 1921. He gives the time required, and the operation for two plates tacked with four spots as follows:

	Time
Tacking and setting up the two parts	2·9 sec.
First welding spot	1·0 ,,
Changing and second welding spot	1·2 ,,
Changing and third welding spot	1·2 ,,
Changing and fourth welding spot	1·2 ,,
Removal	0·5 ,,
Total time	8·0 sec.

Output per hour—450 plates with four spots.
Electrical Energy consumed—1 K.W.H. for 3500 spots or 875 plates.

It must be pointed out again that the savings are seriously affected by the cost of the machine, and can only be realized on mass production work.

CHAPTER IV

Testing Methods*

In pressure welding, the work which is carried out mechanically and without filler material ensures, in the majority of cases, adequate safety in respect of strength and quality of the joint. Subsequent testing of these qualities is easily possible by simple testing methods such as tensile and bend tests on individual pieces taken from the finished article. On the other hand, in fusion welding, conditions are very different. In this case, the properties of the weld seam are not only dependent upon the choice of the construction, the properties of the base and filler materials, but to a great extent on the skill and reliability of the welder. Depending on the workman who is doing the job, the same weld may show different properties. Hence the importance of testing methods in fusion welding is considerable.

If weld joints have to be tested, various processes may be employed corresponding to their position and the purpose for which they are to be used.

The most useful are such tests which make it possible directly to test the skill of the work and the strength of a weld construction as a whole. Those processes are to be preferred which allow the test to be carried out without destroying the weld joint. In certain circumstances, we have to deal with spot tests with a partial destruction of the weld.

Indirectly the suitable manufacture of welded joints may be ensured within certain limits by testing specimen work, and in this case it is usual to destroy the weld seam. Moreover, in this way, information may be obtained regarding the quality and suitability of the welded material as well as the skill of the welder.

Finally, such indirect destructive tests of the weld may enable one to collect data regarding the stresses to which one may subject

* Kemper, "Critical Commentary on Testing Methods for Welded Seams", *Autogene Metallbearbeitung*, Vol. 23 (1930), pp. 119, 218, 234 and 253.

the weld seam under certain provisions, or what is the best place at which to put the weld seam in the construction.

With these points in view we will discuss the various testing methods more closely in the following pages.

Direct Testing Methods without Destroying the Weld Seam

To the first group belong the testing methods which are in general use in engineering practice and which have previously been described for definite jobs, such as hydraulic pressure, steam pressure or air pressure tests for boilers and containers, and loading tests for structures and bridges. Pure pressure and loading tests cannot be regarded as final for welded joints as long as we are in our present state of vagueness regarding fatigue phenomena. The

Fig. 1.—Good gas welding

Fig. 2.—Bad gas welding

compilation of testing methods for this subject would appear to be one of the most urgent research problems of the future.

The quality of a weld seam may be confirmed by a series of special methods without destroying it. The examination of the weld seam and its *External Appearance* may be classified as one of this type. The value of this process should not be disregarded. It will be possible in many cases for an experienced welding engineer to obtain definite conclusions from this method regarding the character of the weld. In this way, overheating of the structure, pores and slag, in so far as they manifest themselves externally, may be recognized, as may also be the cleanliness of the weld, the speed of welding, and the process. Hence conclusions may be drawn regarding the condition of the weld. Figs. 1–4 afford examples on this point, and illustrate a good and a badly welded seam done by gas welding and arc welding. The points of difference may be easily recognized. The gas welded seams are done with backward welding. It is worthy of note that the appearance of these seams only differs slightly from the electrically welded seams, the only external

feature of which is to be found in the scattered splatters of metal. Figs. 5 to 7, and 7 to 12 show further examples. It is, however, by no means impossible for a seam which is externally quite satisfactory not to fulfil the requirements, in spite of its external condition. The determination of the hardness may be regarded as supplementary to a test of this type, and from this test the approximate tensile strength may be calculated. The *Brinell Spherical Compression Test*, which is usually used for this purpose, consists of pressing a steel sphere of a definite diameter at a prescribed pressure into the surface of the base material for a period of time which is also specified. The hardness of the material may be determined from the diameter of the impression, and the tensile strength may be calculated, with fair accuracy, from the hardness number. Shore's rebound hardness test, with the aid of the scleroscope, is of considerable importance for the investigation of built-up welds, since, unlike junction welds, they need not have high tensile strength but should show more resistance to abrasion.

Fig. 3.—Good arc welding

Fig. 4.—Bad arc welding

The most important testing methods for junction welds will now be discussed.

The suggestion has emanated from the University of Wisconsin that the weld seam should be surrounded with a small dam of putty and *Hot Petroleum* should be poured over it. The liquid flows into the flaws of the seam and indicates lack of tightness resulting from pores, &c. The process is the most severe of its kind for testing tightness, but it gives no definite information about the strength of the weld seam.

In addition, a process based on *Acoustic Principles* has been recommended by the Americans, Dawson and Kinzel. With the aid of a listening instrument, similar to a stethoscope, consisting of a rubber sound receiver, two tubular leads and ear fittings, differences in tone which are set up if flaws are present, on striking the seam with a hammer have been registered. The process is said to have proved successful for the testing of boilers, tubes and plates.


Fig. 5.—Unhammered and fig. 6 hammered gas weld forward welding

Fig. 7.—Gas forward welding

Fig. 8.—Correct current strength

Fig. 9.—Current too low

Fig. 10.—Current too high

Fig. 11.—Wrong electrode held too steep

Fig. 12.—Arc too long

Figs. 8–12.—Arc welding

From the results obtained on the testing of steel constructions, the report was less satisfactory, since in these, elastic oscillations vary considerably in their effect. Tests made by us were unsuccessful.

The *Magnetic Testing Method* which has been worked out amongst others by the Frenchman Roux, is based on other principles. The specimen in this test is laid in a magnetic field, and iron fillings are scattered on a sheet of paper laid on top of it. Where a flawless seam exists the iron fillings distribute themselves uniformly. If the welded seam, however, contains cavities, slag inclusions, or junction flaws, the iron fillings congregate at these weak spots, which set up a high reluctance to the magnetic flux in such a way as to cause a diminution in this reluctance. The process has the drawback that it cannot be used for testing vertical or overhead seams, and in addition, it cannot be used for investigating non-magnetic objects. Material stresses, an irregular structure in the material, or non-uniform reinforcement of the weld run, disturb the test and make it unreliable.

Electrical Testing Methods are another type of test. One has been worked out by the American Sperry. This test was at first used for determining material flaws in railway lines, but it can be converted for the testing of weld seams. It consists essentially of passing a heavy direct current through the article which is to be tested. The article is then traversed with three exploring brushes, between which two primary coils of a transformer, wound in opposite directions, are coupled. If a fault occurs between two brushes, and if in this way one coil is more strongly excited than the other, the secondary coil which belongs to both primary coils is excited, and an indicating instrument is operated. Reports of the process vary considerably.

The view has also been expressed in Germany that a handy workshop testing equipment could be obtained based on this or a similar principle. Unger has initiated tests in this direction at the Technical High School, Brunswick, and is said to have evolved serviceable equipment, which may be used for the testing of butt welds and fillet welds, based on *Electromagnetic Principles*. Details about it, however, are not yet known.

The process for investigating welded seams without destroying them, which up to the present time has given the best results, is the process of *Radiation with X-Rays*.* It certainly has the drawback

* Kantner, "The Most Recent Tests with X-Rays in Welding Technology", *Electrotechnik und Maschinenbau*, Vol. 46 (1928), p. 495.

of being expensive as far as equipment is concerned. The application of X-Rays for the testing of materials is nothing new. Several processes of this type have already been scientifically developed. Among these may be mentioned crystal structure analysis, chemical analysis, and the radiation of materials, which, as has already been mentioned, employs hard, short rays. At the present time this is the only process which is of importance for the investigation of weld seams, but experiments are in process for making crystal structure analysis suitable for testing welds.

The process of radiating with X-Rays is based on the fact that a photographic plate or a screen is more intensely illuminated the

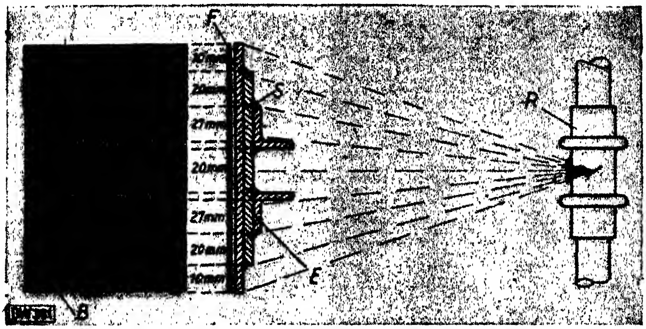


Fig. 13.—Illustration of the impedance o various plate thicknesses to the passage of X-ray

***R*, X-ray tube; *E*, steel construction; *S*, weld seam; *F*, film; *B*, X-ray photograph.**

less the resistance which the X-Rays meet when passing through the article. The variation in the resistance set up by varying material thicknesses in the article may therefore be observed. (See fig. 13.)

The varying density of the material, depending on its atomic weight, also causes differences on the photographs. Aluminium is the easiest material for X-Rays to pass through, and it shows the brightest surfaces on the photographs. It is followed by cast iron, steel, and finally by copper, which affords the greatest resistance and produces intensely dark portions on the photograph. For aluminium, cast iron, and steel, the exposure times are so short that the pictures of thin plates may be projected on the screen. For thicker plates and for materials which are difficult to penetrate, a photographic picture employing a short or long exposure may be made, and this is also necessary if a faulty place is discovered on the screen.

As applied to welding, slag inclusions, burnt portions, cavities, bad joints, graphite aggregations, or cracks may either be seen on the screen as bright spots or on the film as dark spots, since they allow the X-Rays to pass through more easily than the base material. A photograph of this kind is shown in fig. 14, and no further explanation is required. Figs. 15 and 17 show what clear conclusions an expert may draw in this way from the X-Ray photograph. They show the radiation of a good and a bad weld in steel both in elevation and section. The depth at which faulty spots lie may definitely be determined by radiating at an angle (see figs. 18 to 20). Oblique radiation may also be used with advantage in order to discover junction flaws on the bevelled surfaces of V- or X-shaped weld seams. The determination of the depth at which faulty spots lie is facilitated by stereoscopic photographs, which are already well-known from ordinary photography. Fig. 21 shows an X-Ray photograph of a built-up weld and shows that, in the weld reinforçement, a number of small blow-holes is present. From fig. 22 it may clearly be seen how important and significant X-Ray radiation can be for discovering serious damage. The figure indicates a contraction crack in the weld seam of a copper firebox which was hidden from the outside.

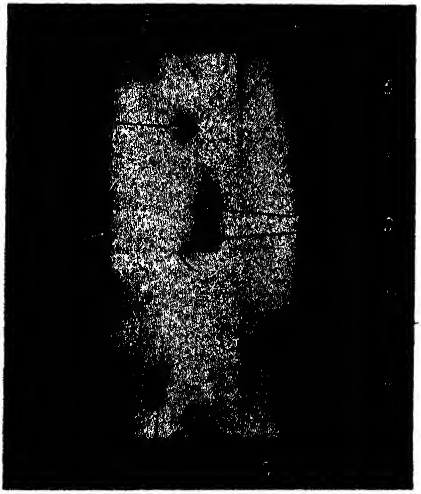
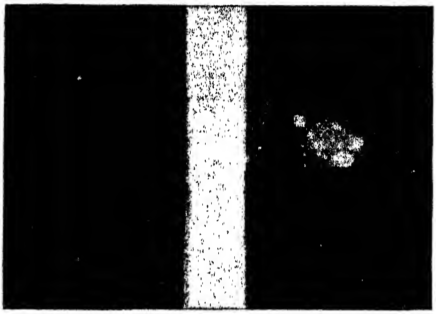


Fig. 14.—X-ray film of a weld with various flaws which are met with

U, Base material; *S*, weld; 1, weld badly joined (sharply defined transition zone); 2, gas blow-hole (dark, sharply outlined spots); 3. blow-hole with slag inclusions (dark, blurred spots); 4, crack (dark, sharply outlined line); 5, graphite aggregations (dark haze).

By examining X-ray photographs faulty places may easily be determined with a little practice. If the course of a crack or the position of a blow-hole on the inside of an article is to be accurately determined, measurement with the naked eye is frequently insufficient for its determination, especially since the sensitivity of the observer to brightness varies and is frequently subjected to external influences. The *Density Testing Method*, for the development of which we have especially to thank M. Schwarz, serves as

a useful auxiliary in the judging of X-ray photographs.* As is shown in fig. 23 it is based on guiding the X-ray negative *g* on a travelling table *h* under an illuminating device, in such a way that



Figs. 15 and 16.—X-ray photograph of a good (left) and a bad weld on steel (right), plan view.

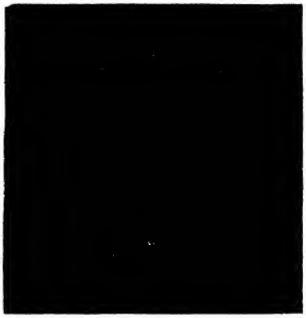
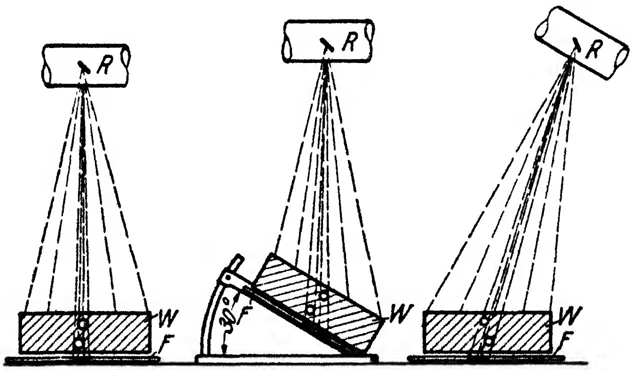


Fig. 17.—X-ray photograph of a good (above) and a bad weld on steel (below). Oblique photographs of the section.

the pencil of rays which is sent out from the source of light *e*, passes through the X-ray negative while it goes by, and after it has passed, can impinge on the photo-electric cell *i*. In this way, the latter is excited and controls the current in accordance with the density



Figs. 18–20.—Determination of the position of flaws by oblique radiation

R, X-ray tube; *W*, material; *F*, film; *oo*, faulty spots.

variations of the X-ray negative, which has been illuminated, so that the mirror galvanometer *d* is made to give a strong or weak kick. These kicks are registered as curves on a photograph with the aid

* Kantner and Herr, "X-Ray Methods for Volume Measurements of Faulty Spots in Material", *Zeitschrift des Vereines deutscher Ingenieure*, Vol. 73 (1929), p. 811.

Fig. 21.—X-ray photograph of a built-up weld taken from the side

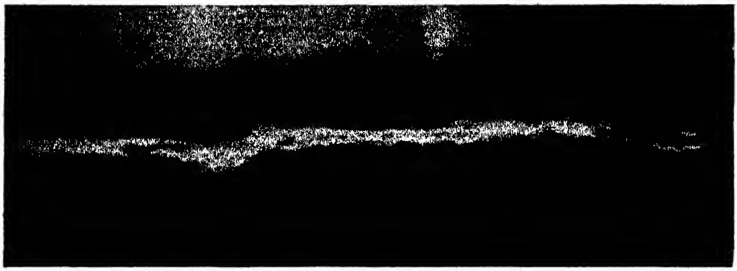


Fig. 22.—X-ray photograph of a boiler weld showing a contraction crack

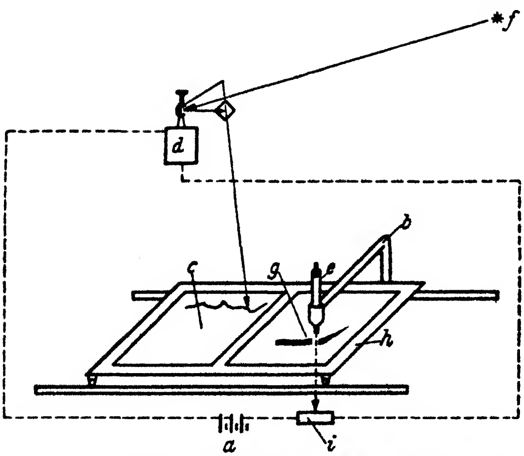


Fig. 23.—Scheme illustration of a Janus X-ray densograph for testing materials

a, Current supply; *b*, illuminating equipment; *c*, indicating paper; *d*, galvanometer; *e*, source of light; *f*, lamp for galvanometer; *g*, X-ray negative; *h*, sliding table; *i*, photo-electric cell.

of a pencil of rays coming from the source of light *f*. In this way we obtain a photograph of the variations in density, that is, the densogram. *c* of the material which is to be investigated. By increasing the voltage in the current circuit of the generator *a*, or by increasing the strength of the source of light *e*, any desired density of negative at the best part of its characteristic may be obtained.

Figs. 25 and 26 show a practical example of a densogram. By means of the curves in fig. 26 the sizes of the faulty spots may satisfactorily be determined from their width and depth.

The first X-ray plants which were put on the market were very expensive and of such a size that they could only be erected as permanent installations. Modern plants, such as that shown in

Fig. 24.—X-ray photograph of a steel casting

The dark spots are blow-holes in the material: ¾ natural size

fig. 27, are not only considerably cheaper, but have also been constructed so as easily to be made portable and may, therefore, be taken to any desired place for testing welds.

It is, however, impossible to determine stresses in the material by this method.

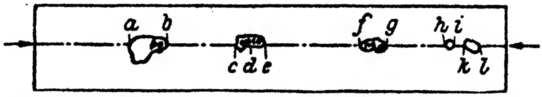


Fig. 25.—X-ray photograph shown as a sketch. Densographic photograph taken of fig. 24 (→←)

a–l, the limit points of the faulty spots

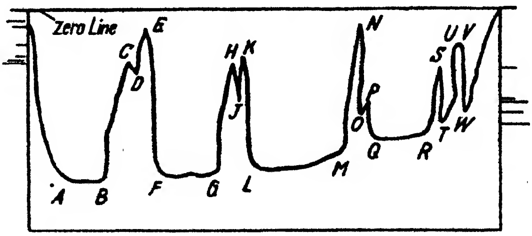


Fig. 26.—Densogram of an X-ray photograph

A–W, degrees of density

Having discovered in X-ray radiation such an excellent means of accurately determining flaws of various kinds in the weld seam, a method in which only the size and unwieldiness of the X-ray equipment provided certain difficulty, it was a short step to employ the electro-magnetic radiating waves, the so-called "Gamma Rays", which are emitted from the radio active elements, for the same purpose in order to overcome this drawback. Since Gamma Rays are very much more penetrating than the hardest X-rays, it was to be expected that their field of application could be extended to even thicker articles than had been possible up to that time by means of X-ray radiations. Only the high price and rarity of radium stood in the way of the application of Gamma Rays. For this reason the experiments of American investigators who employed radium itself or radium emanation have not led to any extensive use of

Gamma Ray radiation. Recently German investigators have used the inexpensive mesothorium for the purposes previously described. This contains about 30 per cent of radium, but is just as efficient for the purposes previously described.

Fig. 27.—Portable X-ray apparatus shown on the test of a locomotive firebox

Gamma Rays and X-rays are similar in other characteristics. Hence it is obviously to be expected that similar results could be obtained with the simpler radium apparatus than with the more unwieldy X-ray apparatus. Experiments * with Gamma Rays, however, have shown that X-ray radiation is more advantageous in three respects, namely:

1. Exposure times using Gamma Rays are considerably longer for testing small or average wall thicknesses (under 3 to 4 in. of steel) than with using X-rays with a tube voltage of about 200 kv.
2. The ease with which large flaws may be recognized when Gamma Rays are used is considerably less than when X-rays are used.

* Berthold and Riehl, " Principles of Material Testing with Gamma Rays ", *Zeitschrift des Vereines deutscher Ingenieure*, Vol. 76 (1932), No. 17, p. 401.

3. Investigations with the help of the screen are impossible because of the diminished intensity of radiation of the rays from radio-active preparations.

On the other hand, Gamma Rays are superior to X-rays in the following respects:

1. At the present time Gamma Rays are suitable for the radiation of large material thicknesses (steel of more than approximately 3 in. thick).
2. The smallest radio-active preparations can be applied anywhere, even in the most inaccessible objects.
3. Since the preparation during the exposure period does not require any supervision, the work which is associated with the investigation is small.

Apart from the above, it is purely a question of cost, and this will decide for one or the other in the future, depending upon whether the development of X-ray or radium equipment leads to greater reductions in cost.

Direct Testing Methods in which the Weld Seam is Destroyed for Testing the Material and the Welder

Our remarks will have shown that, to-day, there is a series of sound serviceable methods which make it possible to test the weld directly without destroying it, but their application is, in many cases, very tedious and difficult, and in others too expensive. For this reason one has frequently to be content with a spot test of the weld seam and with its partial destruction. Zimm suggests that a hole should be bored in places which appear suspicious, when examined externally, so as to expose half the seam, the intermediate and the affected zone, in order to discover flaws in the interior of the weld seam. By etching the exposed portion with an etching medium, the quality of the seam may even better be recognized. After the investigation, the holes are welded up again. Quite recently Schmuckler has constructed a milling apparatus which is especially suitable for this purpose, and this may be attached to any part of the object to be tested either by clamping, screwing, or welding it on by means of a couple of spot welds. This considerably facilitates the making of the test holes.*

* Schmuckler, "Welding Technology in Steel Construction", *Elektroschweissung*, Vol. 2 (1930), p. 236.

This testing method occupies an intermediate position between the direct and indirect methods of testing, and also between the methods of destroying and not destroying the seam.

As long as suitable methods of the former type were not known, one was compelled to adopt testing by destroying the seam. Even where other methods are known, however, testing by destroying the seam still retains very great importance. The latter method makes it possible to test the materials used for construction and the filler materials, so as to see whether they are suitable for welding purposes, and above all, to test welders regarding their reliability and skill. They, therefore, ensure indirectly that good work is carried out.

It would appear that the well-known testing methods for the testing of homogeneous constructional materials could be directly adopted. This would not take into account the special peculiarities of the weld seam. In welding, there are three different zones to distinguish, and these have different structures and can influence testing in a variety of ways. We have the weld seam with a structure having cast characteristics. We have the transition zone, usually having a coarse crystal overheated structure, and we have the zone of the unaffected material. In addition, in certain methods of testing, minor flaws in the weld seam, such as unimportant pores, which only slightly affect the quality adversely because of their position in the test specimen, may act very unfavourably in the determination of the strength properties and lead to wrong conclusions.

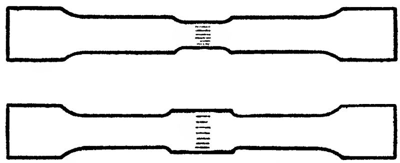
The first property of the weld which has been mentioned shows up very clearly on the *Tensile Test*.

The tensile test is used in the testing of materials for determining the breaking stress, the extension on fracture, and the contraction of area of the material. In the testing of the weld it only gives satisfactory values in respect of the tensile strength because of the zonal character of the weld. Even in this case this is only true provided that the piece fractures in the weld, because otherwise, where fracture takes place in the base material, one only knows that the weld seam has a greater strength than the base material, but one cannot determine how great the strength of the weld is, and to what extent this is conditioned by the weld reinforcement.

The only point in carrying out a tensile test with an unmachined seam is when one wishes to determine whether the weld has the same strength as the plate, and in this way to draw conclusions regarding its behaviour in the construction. If the section of the seam is made

wider or thicker so as to correspond with the percentage of the strength of the plate section which one wishes to reach, one may frequently determine, by carrying out a tensile test in this way, whether the desired property of the weld seam has been obtained. (See fig. 28.)

If the weld material or the work of welders is to be tested comparatively, the weld reinforcement should be removed before the tensile test is undertaken, and the seam should be machined down to the plate thickness, since a specimen with an unmachined seam does not permit any comparison to be made as one can never be sure that one weld seam has exactly the same cross-section as another. Slight variations, which can scarcely be measured, may influence the result. In this connexion, it is advisable to make the weld cross-section of the machined specimen smaller than the section of the plate, so that under any circumstances fracture occurs in the weld.* (See fig. 29.) During planing, however, sharp edges and corners should be avoided, as these may give rise to notch effects. Observation of the fractured place by a macroscopic test makes it possible accurately to investigate the condition of the weld.



Figs. 28 and 29.—Fracture specimens

Even if the tensile test for determining the actual strength gives rise to difficulties, these are much greater if one wishes to determine the ductility or the capacity for work of the weld seam from a welded joint, because of the zonal character of the weld. Each of the three zones possesses a different elastic limit. Moreover, one can draw absolutely no conclusions in respect of the properties of the weld from the total elongation, even when fracture occurs in the weld. Its elongation will invariably only contribute a fraction of the average elongation of the specimen, and the difficulty is intensified if fracture occurs in the base material, as in certain circumstances the total expansion will be taken up by the latter. In any case, for determining the elongation from a tensile test, the best measuring instruments and conversion factors are required, and in spite of these, deceptive results cannot be eliminated. Determinations of elongation of this kind are therefore to be regarded as laboratory tests and better left to specialists.

* Miès, "Concerning the Strength Testing of Welds" *Schmelzschweissung*, Vol. 6 (1925), p. 83.

For the workshop the most suitable process is one which can be carried out by any foreman or even by a welder himself without giving a result which is too far removed from the truth. A testing method of this kind is the *Bend Test.* Admittedly it does not give any figures for the strength of the weld and for this reason its value has been keenly disputed. On the other hand, it is possible to obtain useful information regarding behaviour of highly stressed weld seams, the quality and suitability of the filler material, and the skill of the welder. Since, at the present time, there is no workshop testing method which can be carried out so quickly or can guarantee better results, the bend test has been incorporated in all specifications for the testing of weld seams.

The bend test is usually so carried out that the specimen is either bent in a vice or in a bending jig or a special bending machine, in such a way that the weld reinforcement lies on the outside. In accordance with specifications, the plunger in the bending equipment should be of twice the plate thickness and the pitch of the rollers should amount to five times the plate thickness (see fig. 30). The angle which one obtains on bending the two legs is measured when the first fracture occurs. It should be carefully borne in mind that the weld seam should lie exactly under the plunger so that the former may also be subjected to bending. In spite of this, it is impossible to avoid the bending being extended to the base material of the specimen. For this reason, therefore, any conclusions regarding the strength of the weld seam, as obtained from the bend test, are only imperfect. At the same time, it allows quite satisfactory comparative figures concerning the quality of a weld to be obtained.

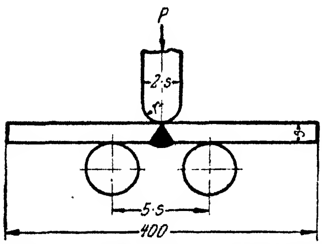


Fig. 30.—Arrangement of the bend test

A better way of assessing the ductility has been suggested by determining the Tetmeyer bend coefficient and not the angle of bend. It has been proved, however, especially when determining the smallest radius of bend, particularly on specimens with reinforcement and complications of this kind, that the variation in the determination of the bend co-efficient is not less than the determination of the ductility from the angle of bend.

Another method consists in directly measuring the elongation of the outermost fibres on the tension side. For this purpose the bend specimens are provided with punch holes or marks. This

method of testing has the advantage that it may be carried out with the simplest equipment.

In certain circumstances it is advisable to bend the specimen in the reverse direction so that the root of the V-shaped groove lies outside. In this way, it may be determined whether the specimen has been completely welded through. This is not always definitely proved if the test is carried out in the way which has been previously mentioned, because in this case, the lower portion of the seam is not stressed in tension but in compression.

In addition, the hot bend test and the forging test should be mentioned. These are advisable when the welded joint is subjected to high stresses when hot. In this way, it may be determined whether or not the weld has become hot short or had its forgeability reduced by unsuitable treatment or by any other constituent which may be present during welding.

The forging test may be intensified by carrying out a *Torsion Test*, and in addition to making the determinations mentioned above, we can arrive at some conclusion regarding the resistance of the welded joint to torsional stresses.

The *Notch Impact* and *Tensile Impact Tests* must to-day be regarded as pure laboratory tests. They are unsuitable as workshop tests, since small variations or faults in the weld, which cannot be entirely avoided but are seldom of serious importance, may easily lead to wrong conclusions. It is therefore advisable to have them carried out by a specially skilled personnel.

At the same time they are of the greatest importance for weld seams which are subjected to rapidly alternating stresses or to impact stresses. The Charpy specimen having a width of about $\frac{3}{8}$ in. has proved itself most suitable for the notch impact test. In this specimen the notch is so positioned that fracture takes place through the weld itself. The structural composition of a welded joint, the type of heat treatment, the distribution of inclusions, as well as the presence of cracks and other flaws, may be obtained from the *Metallurgical Polished Section*. For this purpose, it is almost always necessary to destroy the welded joint. For details the reader is referred to the technical literature.

If an observation of the polished section with the aid of a magnifying glass or of a low magnifying microscope, which is usually good enough for the observation of segregations (non-metallic inclusions), cavities and large flaws, is not sufficient, chemical treatment is necessary in order to show up the structure. As far as the

workshop is concerned, careless preparation and the subsequent penetration of the filler material or junction flaws may be seen clearly enough with the naked eye. A test of the coarse structure at its natural size or with the aid of a low power miscroscope, which is usually carried out after primary etching, is termed a "*Macroscopic Analysis*" (see fig. 31).

A metallurgical investigation affords an excellent test, and this may also be undertaken in the workshop without great difficulty in order to supplement and check bend tests and breakage tests.

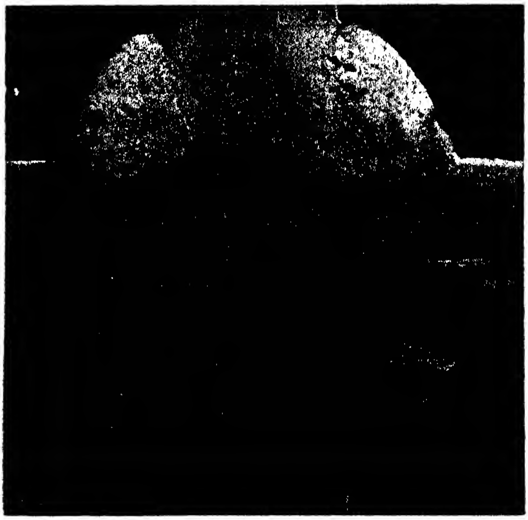


Fig. 31.—Macro-photograph of a fillet weld made with direct current

In addition, a *Microscopic Analysis* permits of an accurate test of the fine structure and makes it possible to arrive at more definite conclusions concerning the structure than does the macroscopic investigation. At the present time they must be regarded as everyday testing methods. Due to the high magnification, the most careful preparation of the surfaces of the section is necessary. The section must be turned through 90° when going from one disc to the other, on each occasion all cracks left by the previous disc being completely removed. During the polishing process care should be taken to remove all particles of iron which have become embedded into the paper on the polishing discs since these cause cracks which cannot be removed on the finer discs. For these reasons, the grinding and polishing discs should not be erected among dirty surroundings.

It is important not to etch the polished sections too soon. This is the reason why polished specimens are so often a failure. If one wishes to bring out the fine points in the structure, specimens, after polishing, should be allowed to lie either for 12 hours in a desiccator (i.e. a container which is filled with calcium chloride which absorbs moisture), or dried in a warm current of air from a "Fön". After ten minutes and a short cooling period, they are then ready for etching.

Simple polishing may bring up the separate crystals in relief. The ordinary etching process has usually the same effect. In general, the following etching media serve for the purposes enumerated.*

Macroscopic Analysis

(*a*) *Steel and Iron*

1. 10 gm. of cuprous ammonium chloride, in 120 $cm.^3$ of water (Heyn's method).
2. Oberhoffer's etching medium; alcoholic hydrochloric acid with the addition of Ferric Chloride, Cupric Chloride and Tin Chloride (Stannous).
3. Heyn, Bauer, and Baumann's process for indicating sulphur.

(*b*) *Copper*

1. Ammonia.
2. Alcoholic Nitric Acid.

Microscopic Analysis

(*a*) *Steel and Iron*

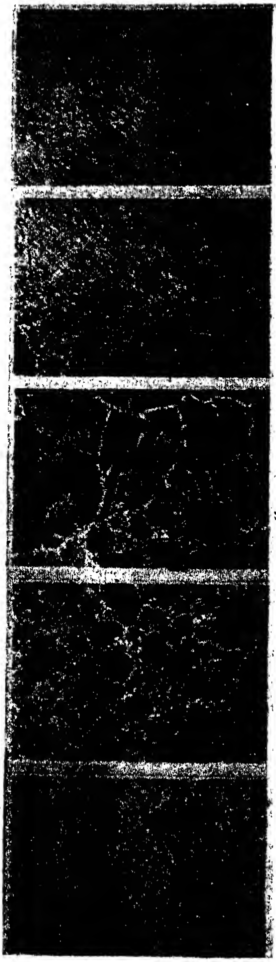
1. Nitric Acid solution in Ethyl Alcohol.
2. 10 per cent Nitric Acid solution in Isoamyl Alcohol.
3. Alcoholic picric acid—4 gm. of picric acid in 100 gm. of ethyl alcohol.
4. A solution of sodium picrate in water.

(*b*) *Copper*

1. Ammonium persulphate.
2. Cuprous ammonium chloride with ammonia.

* *Handbook of Materials*, Vol. 11 (Iron and Steel), and *Handbook of Materials*, C. 13/14 Non-ferrous Metals (Beuth-Verlag, Berlin).

The etching time differs with various etching media and is, in addition, affected by the composition of the test specimen. Frequently a short period of immersion is sufficient. For low concen-

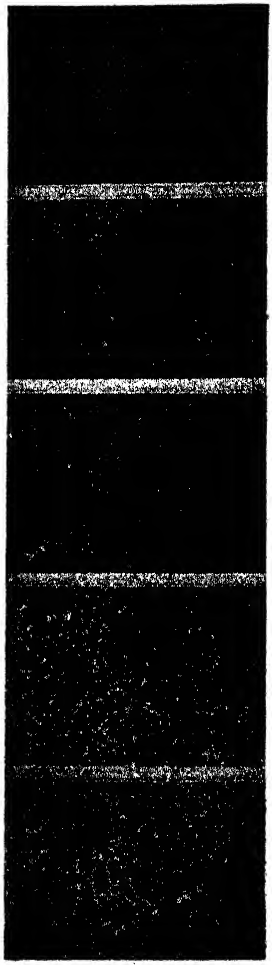


Weld

Transition Zone

Base Material

Figs. 32–36.—Micro-photographs of a gas weld



Weld

Transition Zone

Base Material

Figs. 37–41.—Micro-photographs of an arc weld

trated solutions we have to deal with times of from 1 to 15 min. Electrolytic etching is frequently used for developing the micro structure of steels which are highly resistant to attack.

After etching, the specimen is immediately held in running water and briskly rubbed with a damp wad of cotton wool, in order

to remove any depositions of the etching liquid. After washing with water again and dabbing with a wad of cotton wool, which has been dipped in alcohol, and after careful drying, the surface of the polished section may be observed under a metallurgical microscope. As a

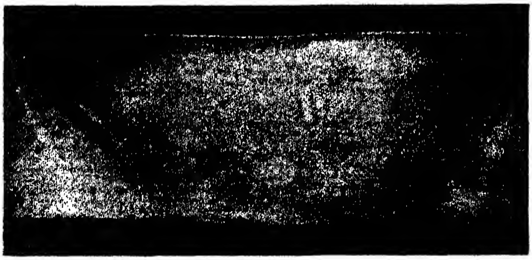


Fig. 42.—Macro-photograph of an electric hot weld

rule, vertical illuminators, total reflecting prisms or even plain parallel glasses inclined at an angle of 45° to the axis of the microscope, are used for this purpose. The polished sections should be kept in a desiccator.

Fig. 31 shows the macroscopic photograph of an electric weld which has been made with direct current on a cruciform specimen, similar to those which are made for a test of welders. The regularity of fillet welding in respect of the depth of the runs and good penetration may be clearly seen. The slight formation of pores, which cannot be entirely avoided in electric welding, is characteristic.

Fig. 43.—Macro-photograph of a cast-iron cold weld

Figs. 32 to 41 show test welds, one of which was carried out by gas welding and the other by electric welding, as made on steel with a carbon content of 0·33 per cent. The flowing together of the filler material with the base material and the gradual transition of the good weld may be clearly seen. Since welding was done in several runs, the coarse grained filler material has experienced a change in grain from its typical cast character, and this closely approximates

to a refining of the grain. Due to overheating, a coarse structure is always formed in the transition zone of the plate, and this is especially the case with gas welding. The grain becomes gradually finer until ultimately it merges into the base material, which is uninfluenced by the heating effect of the welding.

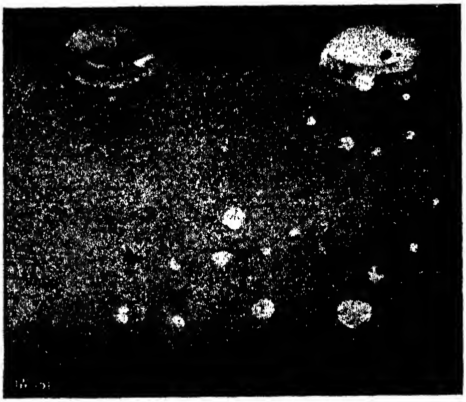


Fig. 44.—Macro-photograph of an electric built-up weld using steel wire electrodes

The regular structure of a good electric cast iron hot weld may be seen from the macro-photograph in fig. 42. At the same time, the irregularity of the joint of an electric cast iron cold weld, using steel wire, stands out very clearly in fig. 43. Fig. 44 shows an electric built-up weld in cast iron using steel wire. The surrounds which penetrate well into the parent metal may be seen. The white cast structure which results and which is difficult to machine stands out, and further mention is here made of its brittleness.

The macro etching of a copper weld is shown in fig. 45. In this way the X-shaped welding groove, together with the excellent junction with the base metal, is clearly shown up. In addition, the varying composition of the two plates which have been welded is shown on the photograph of polished section, and one of these shows a large number of impurities.

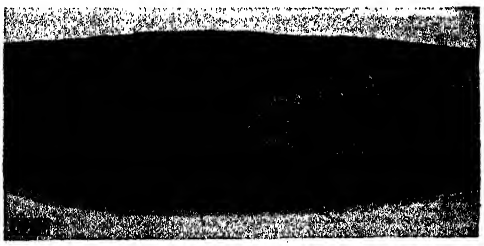


Fig. 45.—Macro-photograph of a copper weld

Figs. 46 and 47 show the fine structure of two copper welds which have been treated in different ways. The former was hammered cold in conjunction with the welding. The lines of slip, which are set up by cold working, correspond in their direction with the crystalline orientation of the grains. Some blisters and copper oxide inclusions stand out as well. The photograph was taken from the middle of the weld.

Fig. 47, which was also taken from the middle of the weld, shows the appearance of a specimen which was hammered hot, probably at a temperature of 1100° F. (600° C.). Two adjacent

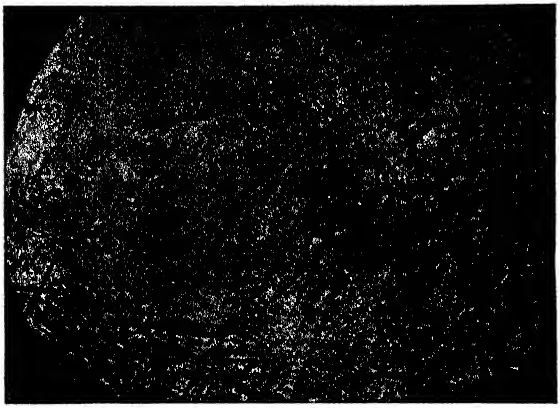


Fig. 46.—Micro-photograph of a cold-hammered copper weld

zones having different states of stress stand out. Recrystallization may be considered complete. Blisters and oxide inclusions are also present in this case.

Fig. 47.—Micro-photograph of a hot-hammered copper weld

Along with the metallurgical investigation, chemical analysis is necessary in many cases. By accurate weighing, the proportion of materials present in the iron may be determined. The chemical composition is frequently of exclusive importance as far as the

weldability is concerned, and therefore requires special investigation.

Indirect Testing Methods in which Welded Parts of a Construction are Destroyed

Final tests on the completed experimental designs of constructions are of great importance in order to determine what stresses the selected design will stand, or what arrangement ensures the greatest safety on various designs.

There are already methods of note suitable for such investigations, to which reference can be made in the construction of welded joints and these will serve as a good guide for further jobs.

Thorough tests were carried out many years ago in Germany on water gas welded boilers which were subjected to an internal pressure which was increased gradually until fracture of the plant occurred. At the same time, the boiler was made smaller by cutting out separate sections and welding in others, and the phenomenon of fatigue, the effect of normalizing the weld seam by annealing the boiler, and the subsequent forging of the weld, were carefully investigated from the portions which had been removed. Such tests may be also carried out on boilers which have been manufactured by the gas welded or the electric arc welded processes.

In this respect, Der Schweizerische Verein von Dampfkesselbesitzern (The Swiss Steam Boiler Owner's Association) with the special co-operation of Höhn, who carried out a series of tests on welded vessels, has proved of great service. The publications and the yearly Report of the above-mentioned Association of 1923 are concerned with tests of this kind on experimental vessels of varying shapes, dimensions, and plate thicknesses, and these are very instructive to the steam boiler constructor. The welding was carried out with both gas and electric arc. Some of the seams were welded from the outside and afterwards on the inside, others were welded on both sides simultaneously with a heavy reinforcement. The strength and tightness of such seams with skilful workmanship were excellent, so that fracture invariably took place in the plate itself. On the other hand, it was once more shown from these tests how dependent one is on the reliability and the skill of the welder, since in some cases less satisfactory results were recorded.

In order to test the safety of welded joints in steel construction

the Gutehoffnungshütte, among others, in the year 1923, completely welded electrically a double-sided lattice girder of 32 ft. 6 in. span and about 3 ft. depth, and fractured it under static stress by gradually and uniformly increasing the load.

The test showed that no weld seam cracked in the direction of the load in the member, and consequently fusion welding is not only intrinsically sound, but provides a joint which is much stronger than a riveted joint and this has also been confirmed from laboratory tests on individual members. Similar tests with the same results have also been carried out in other places.

As far as shipbuilding is concerned, we would mention the tests which were carried out by Strelow at the Deutsche Werft, Hamburg. A boom 48 ft. 6 in. long, which was welded together out of five plates, was loaded until it buckled. This also occurred outside the welds, and in this way the adequacy of welding was demonstrated. In addition, a welded stern post having a nett weight of 3·2 tons was subjected to a variety of drop tests from a height of 5 ft. to 11 ft. which it withstood without damage although impact loads up to 190 tons were set up in the post.

As far as railway work was concerned, it had to be decided how far one could go in the repair of vehicles and with the welding of highly stressed parts which are subjected to severe wear and tear. In this category we have on carriages, the axle box webs, the longitudinal girders, the diagonals, the buffer faces, and the buffer sockets, &c. On two test wagons these members were cut through beforehand and welded electrically and by gas welding. The carriages were then heavily loaded and allowed to collide with a fixed tender at a speed of 25 miles per hour. They were then put for a long time into normal service on an inclined runway where the greatest stresses occurred during service and the welds were not damaged.

A multiplicity of laboratory tests, which are intended to give definite information as to how welding should best be carried out, have been drawn up. As an example Höhn has designed a special breaking jig in order to test the various welding joints which frequently occur in steam boiler construction. Fig. 52 shows a jig of this type for the testing of flanged joints on pipes and figs. 48 to 51 the shapes of designs which have been tested with it. The results were that the breaking loads of these four joints were related in the form a : b : c : d = 100 : 95 : 75 : 45. The average breaking load with the design shown in fig. 48 amounted to 68·4 tons.

Other tests were put in hand on reinforcing straps on sections

cut from vessels, on welded straps on tensile specimens, and on plates welded to one another at right angles, in order to find the most suitable design. In the drafting of the specification for welded steel structures (D.I.N. 4100), which has already been mentioned, tests of this type were first carried out in order to determine whether the permissible stresses which were fundamentally applicable for calculations, were satisfactory. A series of multi-member joints and material joints of various types were welded by a good welder and fractured by increased loading. In the majority of cases the result was that the breaking load was well above the calculated load. In isolated cases, however, the arrangement selected was not suitable.

Fig. 48 Fig. 50

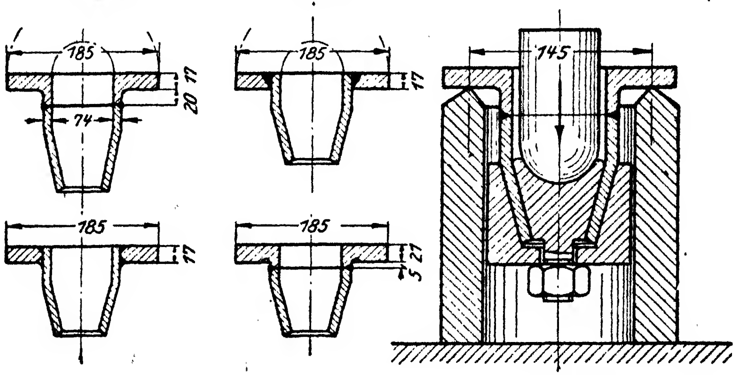


Fig. 49 Fig. 51 Fig. 52

Figs. 48–52.—Testing of flange joints

At the present time one has no experience of the effect of the phenomena of ageing and fatigue on welds in the course of years. In this respect there is a certain danger. Tests which may be drawn up to deal with this point are, therefore, of special value.

A new railway sleeper joint, designed by the State Railways, in which a backing plate had to be welded on to the sleeper, was subjected to a test of this kind. Since primarily dynamic effects are to be expected from rolling stock, alternating stresses were applied in various directions in order to investigate whether the phenomena of fatigue occurred. The impacts which are set up by the curving movements of the vehicle were imitated by applying a large number of blows with a compressed air hammer, an impact pendulum, and a drop hammer, and the alternating bending was imitated by means of a spring testing machine. The result of the tests was entirely

satisfactory. Spindler * gives another example. We are concerned now with fatigue tests on riveted and welded constructional members of lorry frames which Spindler put in hand in conjunction with the firms Mannesmann-Mulag and Boehler-Stahlwerke. Figs. 282 to 285 show four experimental designs on which the tests were based. In the journey of a lorry the longitudinal and lateral girders are subjected to distortion, and it was desired to know by means of time tests how these stresses manifested themselves in the course of time as fatigue phenomena.

The results of the tests were that in the riveted joint (fig. 53) the rivets became so loose after approximately 120 swings of a counterbalanced baulk that the riveted parts of the plate were pushed together about $\frac{1}{64}$ in. with each swing. After about 600 swings, the plate joint at the rivets had about 4 to 6 thousandths of an inch clearance, and after a further 700 swings up to 8 thousandths of an inch clearance, and finally the plate fractured in the dangerous cross-section after a total of about 2000 swings.

No rivet fracture occurred, but the fracture occurred in the material due to overloading the frame, since the overhanging joint which was hanging loose in the rivets was subsequently bent.

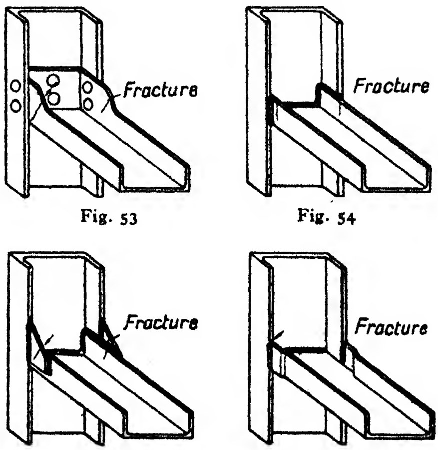


Fig. 53 Fig. 54 Fig. 55 Fig. 56

Fatigue tests on riveted and welded motor-car parts

The welded joint shown in fig. 54 withstood 5400 swings, and that shown in fig. 55, 6500 swings. In the former case the material in the overheated zone near the weld seam fractured, and in the other cases fracture occurred in the gusset plate and in the material which had been unaffected.

The joint shown in fig. 56 behaved worst, and in this type the welded joint fractured in the flange after a short time.

In conclusion, an example will be mentioned from the large number of American swing and impact tests, and this deals with a

* Spindler, "Riveted or Welded Carriage Frames", *Motorwagen*, Vol. 31 (1928), p. 102.

swing test which was carried out by the Westinghouse Electric and Manufacturing Co. on riveted and welded experimental designs for

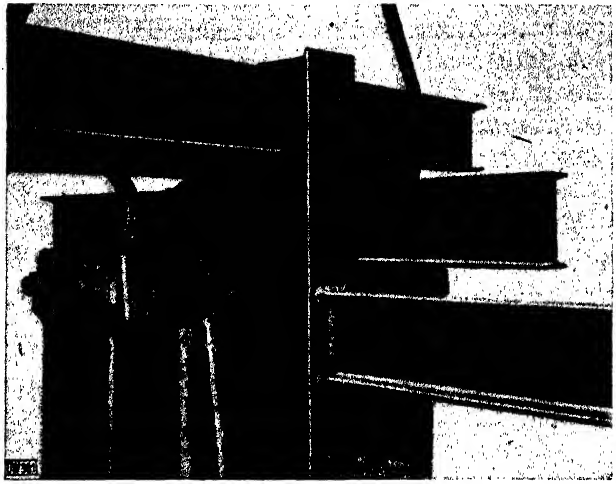


Fig. 57.—Welded test piece before the swing test

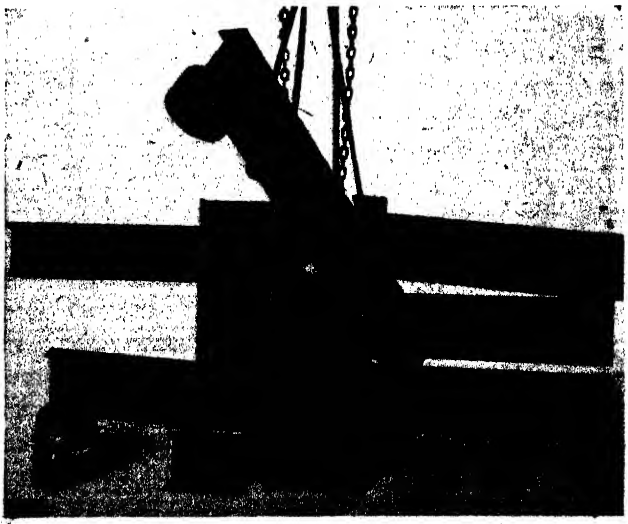


Fig. 58.—Welded test piece subjected to intense loading from a girder after the swing test

steel construction. Four I 15 joists, 18 ft. long, were respectively welded, and riveted to each of two double Tee girders, N.P. 25. The welded design is shown in fig. 57. The test pieces were fixed

on the baseplate of an oscillating machine and tested by means of this. Even after 1 hr., two of the connecting angles of the riveted design were fractured. After 2½ hr. two of the riveted girders were completely loose, and after 3½ hr. the remaining two were completely loose. Among the welded constructions, none of the welds showed any change after 18½ hr. On hitting them with a hammer the members gave a clear tone. Only after the welded members were loaded with a heavy weight of 25 lb., in order to shorten the tests, did fracture occur, after approximately 1 hr. in the material surrounding the section which had been welded on (see fig. 58). In this way, the superiority of welding as compared with riveting against fatigue stresses may be shown so that it appears quite sound to weld steel buildings which are subjected to heavy vibrations.

CHAPTER V

Accident Prevention

Welding is subject to dangers to a greater extent than any other manual or manufacturing activity, and these may lead to serious accidents not only for the workman himself, but also for those in his locality, and accidents may be accompanied by more or less serious damage to equipment. There are, therefore, a series of regulations and specifications foı guarding against accidents,* which every workman must know and observe. Bearing in mind the importance of a knowledge of these dangers and the importance of combating them, a brief report is made of them here.

By far the majority of accidents occur due to the ignorant operation and maintenance of the plant. Others, which are more rare, are due to faults in the plant itself. In addition, the activity of the welder and even numerous properties of base materials, as well as the conditions under which they must frequently be welded, provide further sources of danger.

As far as the possibility of accidents, which may be caused by the ignorant operation and maintenance of the welding plant, is concerned, we may say that these dangers are very great in gas welding and in cutting, since the formation of an air-gas or oxygen-gas mixture provides a permanent source of danger, which may manifest itself in an explosion in the *Generator*, an explosion in the building, or an explosion in the cylinder.†

Explosive mixtures may easily be formed in any generator when it is first put into commission since at this period it is generally filled with air, which has first to be gradually forced out by the acetylene gas which is generated. Hence, when a generator is put into service,

* Regulations for the manufacture, storage, and use of acetylene as well as for the storage of calcium carbide. Regulations on the transport of liquefied and compressed gases. Specifications for care against accidents of the German Iron and Steel Association for Welding and Cutting plants working with compressed gases. Specifications and Standards of the Association of German Electrical Engineers.

† Kleditz, "Accidents and Accident Prevention in Autogenous Welding and Cutting", *Schmelzschweissung*, Vol. 8 (1929), p. 72.

and before welding or cutting are started, one should wait long enough to ensure that pure acetylene gas is being supplied. In addition, dangerous acetylene air mixtures of this kind may be formed during service in the generator, should air enter the apparatus during sludge removal or filling. Apparatus which prevents this is, therefore, to be preferred.

The most dangerous are oxy-acetylene mixtures which are formed when the oxygen gets back through the torch into the acetylene line and reaches as far as the generator. This phenomenon is frequently associated with a back fire. Entry into the acetylene line can only take place if the hydraulic valve, which is prescribed by law and which should prevent its going as far as the generator, is either not present or loaded beyond the cubic feet/hr. loading, corresponding to its construction, or if it is not in satisfactory working condition. It frequently happens that the safety valve is not sufficiently filled with water or it may allow water to escape. Cases where the welder, due to negligence and ignorance of the danger, works without a hydraulic valve, are more infrequent.

The presence of an explosive mixture in the generator does not give rise in itself to the danger of an explosion. It only occurs if, in any manner, the gas mixture is ignited. There are, however, a series of factors which may give rise to an ignition of this kind both during service and during the maintenance of the plant. One of the most frequent causes of an ignition is a back fire from the torch which cannot be held up if the hydraulic valve fails to function. Hence, attention should be paid to keep this in good order. A second cause of ignition is provided by the heating up of carbide dust. Carbide dust, when thrown into water, forms into lumps and gradually heats up to red heat. For this reason, apart from special generators, charging should be confined to granulated pieces of carbide which are as free from dust as possible. Even these may be brought up to red heat if the necessary quantity of water required for complete decomposition is not available. This may occur if the lumps get embedded in carbide sludge and come into contact with water again when the sludge is removed. Especially during the cleaning of the apparatus the danger of an explosion is present. Inadequate cleaning or generating, or a too-heavy filling of the feed basket of " water to carbide " equipment, may result in an accumulation of sludge. This covers up the pieces of carbide, and in this way they may be a source of danger.

In addition, numerous explosions are caused on generators working

radiating fractures which went very deep, and these were due to faults of manufacture.

For an explosion of the cylinder contents it is necessary to have an explosive mixture, and the possibility of an ignition occurring, just as in explosions in generators. Mixtures of this kind are occasionally present in cylinders in which the oxygen was obtained by a chemical process from water, and was therefore obtained simultaneously with hydrogen. In this way an explosive gas, which is a mixture of both gases, may be formed. Since oxygen is almost entirely

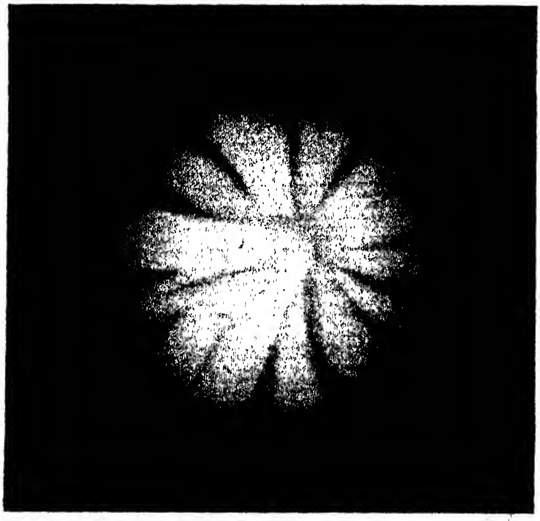


Fig. 1.—Test of a cylinder: X-ray photograph of the base of a cylinder

obtained to-day by the physical process from liquid air, and since this is only made slightly impure with nitrogen, the danger that explosive mixtures may occur in oxygen cylinders only exists if oxygen and hydrogen cylinders are mixed up during filling. One can protect oneself against this danger by means of the so-called "soapy-water" test. This consists of leading oxygen from the cylinder which is to be tested, at low pressure, through a hose into a dish, which is filled with soapy water. If the bubbles which rise are ignited they should burn silently, if the oxygen is pure. They explode, however, with a light report which can be heard if an explosive gas mixture is present. Up to a short time ago the mixing of cylinders was possible in spite of the regulation that oxygen cylinders had to have a right-handed thread and hydrogen cylinders

a left-handed thread. Nowadays it has been laid down that the connecting piece on oxygen cylinders has to be about $\frac{3}{16}$ in. larger in diameter than the connecting piece on hydrogen cylinders so that mixing of this kind does not occur at charging stations.

The possibility of an ignition is also provided when the pressure reducing valve is burnt out, or if the cylinder valve comes in contact with fat or oil. The friction of a high-pressure discharge of oxygen is sufficient to cause an ignition. A so-called burning-out guard pro-

Fig. 2.—Test of a cylinder: Plan view of the cylinder base after cutting through the cylinder

vides a protection against burning out the pressure reducing valve, which is caused by the heat of compression when the valve is opened. This is the type which is shown in the section of the pressure reducing valve (see p. 45). It has been previously stated that oil and grease must be kept away from oxygen valves, and that even touching them with greasy hands may be dangerous.

If pressure reducing valves freeze due to the cold set up by expansion, the same remarks apply as apply to the thawing of generators. For this purpose only hot water or hot cloths should be used and never flames or red hot metal. Electrical equipment for protection against freezing, which acts as a small resistance oven, has proved satisfactory, and it may also be fitted even on batteries

or cylinders. Its use depends on a source of current being available.

Finally, danger may also be caused by gas lines and gas hoses. One cause of explosion is to be found in the hoses getting filled with an explosive mixture due to oxygen getting back from the torch. The possibility of an ignition is provided by a back fire due to the torch becoming choked or due to its being in faulty condition, or in addition, as a result of a careless search for leaking places. In this way, the gas lines are frequently set on fire, and this may lead to an explosion. The correct way is to brush the line with soapy water in order to find out whether there are leaking places or to put the hoses under an air pressure test under water, and this should be done at least once a month.

If the gas lines have to be cleaned, and this should be done from time to time because of the dirt which may be introduced by particles of rust or of soot, formed by the decomposition of the acetylene, blowing out the line must always be done in the direction from the generator to the torch so that explosive mixtures are not sent into the generator. It is absolutely wrong, therefore, because of a shortage of compressed air, to use the oxygen which is under pressure in the cylinder, for blowing out purposes. Even this has occurred, although it may seem hard to believe.

The dangers which threaten the welder in *Electric Welding* are less than those in gas welding. In the former, accidents generally are only caused by catching oneself in the machine or by making contact with low-voltage equipment.* Accidents may be avoided by keeping all insulation in good condition, and by preventing the welder from coming in contact with any equipment which is carrying current by suitably wrapping the latter. In addition, attention should be paid to earthing the frame of the machine and the work soundly. The work should not be put on supports which provide a higher resistance to the current than does the welder's body. It is advisable for the latter to insulate himself to earth, and this can be done by means of wooden shoes, leather shoes having wooden soles, or by means of a wooden mat or frame. If welding has to be carried out on boilers, containers, ships, or on steel frames where there is a danger that the welder may provide a good conducting

* Neiss, "The Causes of Electrical Accidents in Arc Welding Equipment and How to Guard against Them", *Schmelzschweissung*, Vol. 6 (1927), p. 196.

Fritz, "Protection for the Electric Welder", *Schmelzschweissung*, Vol. 6 (1927), p. 153.

connexion to earth, by coming in contact with metal parts, then welding ought at least to be done with alternating current.

Workmen who are very sensitive to electric shocks should preferably not take up the calling of an electric welder.

In the *Welding Process* itself, the welder and those in the vicinity are exposed to danger from flying sparks and from arc rays, and in certain circumstances, from the heat which is radiated from the work. For this reason, to protect the body against showers of sparks, suitable working clothing should be provided, which in special cases, should serve as a protection against heat. This consists of a closely fitting fireproof suit, leather shoes with wooden soles, gloves, the surface of which is made of leather, or gloves which are entirely made of leather or asbetos.

Special protection is necessary for the eyes. The gas welder requires goggles with dark glasses for this purpose, and these protect the eyes against the blinding light rays and also against sparks and splutterings of metal. It is better for the electric welder to use a face shield. Since he has one hand free during welding he can do this. If his face has also to be protected against heat rays as is the case in hot welding with the arc, a face mask with protection for his neck and shoulders takes the place of goggles or a face shield.

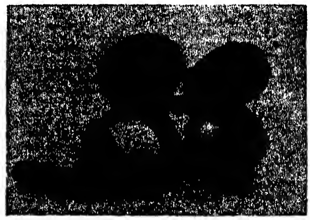


Fig. 3.—Protective goggles

The goggles should fit the face well so that light rays from sparks do not hit the eye from the side. In addition, they should not possess any metal parts which touch the skin and which will become warm from the heat which falls on them during welding, but the frame of the glasses should be made of Presspan or leather. The glasses should be easy to change. As far as their colour is concerned, we have already said all that is necessary.

Goggles have recently been so designed that the welder may lift up his glasses during interruptions in the welding in order to cool his eyes, and in this way he can look after his other gear much better than is permitted with coloured glass. Fig. 3 shows goggles of this type. This type is willingly used by welders. At the same time there is a considerable disinclination to use the light protective cap as well as the heavy protective hood, the former of which has a frame which can be fitted on and fixed to the head by means of a rubber band. The face shield may be dangerous if the welder touches

which the generation of gases is even less. Since, however, the gases are irritating, care should be taken, where it is possible, to provide good ventilating equipment over the welding places.

On the other hand, a further source of danger may be introduced by the properties of many materials or objects which have to be welded, and these may be harmful to the welder.

In the *Welding of bronze, brass, zinc, tin and lead*, gases are formed which are very dangerous and from which the welder must be protected by the provision of breathing masks (respirators), and this point was stressed during the discussion on the welding of these metals and alloys. The greatest care should be taken that these regulations are not broken as a result of negligence.

The same danger may be introduced during work on containers which have a coat of lead paint, and this should be carefully removed before welding or cutting work is undertaken.

In these circumstances also the provision of respirators as a protection against the lead vapours which are generated, is compulsory under Factory Regulations. The danger of lead poisoning is intensified since lead does not betray itself either by taste or smell.

A further danger is threatened in *Containers which have held mineral oils, benzine, or gases*. There is here the great possibility of danger from explosions. A large number of fatal cases have been recorded which have been due to lack of care on such work. The remaining traces of oil and benzine vaporize on welding and form an explosive mixture with the air in the container and this is ignited with the welding flame. It is not sufficient merely to clean out the traces thoroughly, but additional precautions must be taken. The Regulations of the Norddeutsche Eisen- und Stahlberufsgenossenschaft (North German Iron and Steel Association) for welding and cutting plants, working with compressed gases, lay down the following Regulations: " When welding and cutting work is carried out on vessels which have contained tar, oil, benzol or any similar combustible liquid, an adequate supply of hot and cold water or soda lye must be available. Moreover, when such work is carried out on vessels which have contained an explosive gas, sufficient quantities of steam, carbon dioxide, compressed air, or water for washing out and filling the vessel must be available. The insured parties are responsible for removing from such a vessel, before welding, any traces which may be present and also for carrying out a thorough washing and for maintaining connexions to the vessel open even during welding."

One is in a much safer position if, in order to remove any explosive mixture during welding, one fills the container with water, where this is possible, and only has sufficient air space to leave the portion, which is to be welded, free. On small vessels, from which water may easily be emptied, there is, as a rule, no difficulty.

Explosive gas mixtures may even be formed by the acetylene welding flame, and in the welding of hollow vessels they may prove dangerous. In the neighbourhood of the illuminating portion of the flame, mostly hydrogen and carbon monoxide are formed if the welding flame is held at right angles to the weld zone and at a short distance from the latter. If these gases mix with the air which is present in the inside of the hollow vessel, they may even give rise to an explosion. The habit which the welder has of lighting the combustible gas on the welded article while it is still red hot may lead to the formation of oxy-acetylene gas mixtures, and these may explode in confined spaces if the torch is not lit and the gas passes out unused.

It is, of course, obvious that on such work in hollow vessels care should be taken to ensure an adequate supply of air or oxygen so that there is no danger of suffocation due to nitrogen or other causes.

PART III

Gas Cutting

Gas cutting, which is also called autogenous cutting, is a German invention made in the year 1905. During the following years the invention spread rapidly over the whole world. It serves the purpose of cutting up articles quickly and cheaply by means of a sharp, clean cut. For this purpose a specially designed torch is required, the cutting torch. Articles may also be cut up by means of the welding torch flame or with the arc, but this work cannot be called " cutting ", but is merely a process of melting through. In these cases the cut gap is wide and dirty. Experiments to make clean cuts with the arc have frequently been put in hand, but up to the present, with the exception of the so-called electric cutting saw, they have not led to practical results. Even this method does not seem to have made much headway in practice as compared with the simpler and cheaper cutting torch which is employed.

Gas cutting with the cutting torch is based on the fact that, in a jet of oxygen, steel burns vigorously if it is brought up to its ignition temperature. The oxygen, which acquires a high velocity and takes on the shape of a jet by passing through suitable nozzles, also serves the purpose of removing the burnt particles of iron. The cutting process, therefore, consists of three separate processes: (1) the heating of the iron up to the ignition temperature, (2) the burning of the iron in a jet of oxygen, (3) the removal of the burnt particles of iron by means of the jet of oxygen.

Gas cutting may only be completely used on steel and cast steel, and to a limited extent on cast iron. Two conditions have to be prescribed before metals can be cut in this way. Firstly, the ignition temperature of the metal must lie below its melting-point and secondly, the oxide which is formed must fuse more easily than the

metal. If the ignition temperature lies above the melting point, the metal melts before it arrives at the stage of combustion. A clean cut is then impossible. If the melting temperature of the oxide is above that of the metal, an oxide also forms on the cut surface and this prevents continuous cutting work.

In addition, it is desirable that the metal should not possess too high a heat conductivity so that the heat is not conducted from the point of cutting, to such an extent that the temperature of this point sinks below the ignition temperature. The oxide should also be easy flowing, and possess as low a specific weight as possible, so that it may easily be removed by the jet of oxygen.

Copper and aluminium and their alloys, as well as the remaining light metals, do not fulfil these conditions. For this reason gas cutting is not applicable to them.

Ease of Cutting Alloy Steels.—The question whether, and to what extent, alloying constituents in steel influence the ease of cutting, is very important. A detailed investigation has been carried out on this matter by the I.G. Farbenindustrie A.G. in Frankfort-on-Maine (Griesheim).* The results show that a content of iron carbide (Cementite) and graphite, with highly alloyed iron-carbon-alloys, makes cutting difficult. An alloy of this kind, in certain circumstances, may only be cut after considerable preheating.

On the other hand, a manganese content in iron alloys simplifies cutting since this in itself is easy to cut. Austenitic manganese steel with 13 per cent manganese and 1·3 per cent carbon is extraordinarily easy to cut, whereas it cannot be machined by planing, milling, &c.

Silicon alloys, with up to 4 per cent silicon, are also easy to cut, but silicon diminishes the cutting speed if the carbon content of the alloy exceeds 0·2 per cent. With higher carbon contents the alloy loses its ability to be cut.

A chromium content up to 10–20 per cent makes the alloy unable to be cut. Alloys with lower chromium contents have shown that they may be cut cold.

Nickel steels, having a nickel content up to 34 per cent, are easy to cut. Above this limit the ease of cutting diminishes considerably.

Copper steels with up to 0·7 per cent copper behave like ordinary structural steel.

* Wiss, "Concerning the Application of Autogenous Cutting in the Complete Manufacturing Trades", *Autogene Metallbearbeitung*, Vol. 22 (1929), pp. 46, 74, 90.

Alloys with tungsten may easily be cut cold if the tungsten content does not amount to more than 10 per cent. They may also be cut hot with a tungsten content up to 17 per cent. After that they are no longer capable of being cut.

Within commercial limits, phosphorus and sulphur do not effect cutting.

Gases for Cutting.—For preheating the weld oxygen mixed with a combustible gas is necessary. For cutting, oxygen of high purity is required. Initially hydrogen was exclusively used as a combustible gas, since this has the widest application for cutting (up to 40 in. material thickness). In recent years, most people have gone over to the use of acetylene as the heating gas and this is suitable for the majority of cases (up to 24 in.). It is admittedly necessary with acetylene to adjust the heating flame very accurately and to keep the flame at a definite distance from the work, so that it requires definite experience and practice on the part of the cutter. At the same time, it has the advantage that it is available in almost every workshop where it is used for welding purposes, and this is not always the case with hydrogen.

In addition to acetylene, the combustible gases, benzol and benzine vapour, may be used for preheating. The equipment which is necessary for this purpose has the advantage of considerable simplicity and cheapness. Benzol vapour itself is cheaper than hydrogen and acetylene, but this advantage is neutralized because of the increased consumption of oxygen.

Illuminating gas is quite suitable for cutting thinner plates (up to 6 in.). Even unskilled workmen can make a smooth cut with it. The cutting speed, however, with illuminating gas is less than that with acetylene, and in addition, a longer preheating time is required.

The degree of purity of the oxygen exercises a definite effect on the cutting output. The tests which were put in hand in 1927 by the Chemisch-technische Reichsanstalt (The Chemico-Technical State Laboratory) in conjunction with the Schweisstechnische Versuchsanstalt des Reichsbahn-Ausbesserungswerkes Wittenberge (The Technical Welding Research Department of the State Railway Repair Workshop, Wittenberge) have given information relating to this matter.* The illustration of the curves in figs. 1 and 2, which were obtained from the tests, show to what extent the time

* Rimarski, Kantner and Streb, "The Influence of Oxygen Purity on Cutting by means of Oxygen and Acetylene", *Autogene Metallbearbeitung*, Vol. 21 (1928), p. 3.

and the oxygen consumption increase during cutting, on account of the impurity of the oxygen, and in addition, they show how these depend on the working pressure.

The Cutting Torch.—Cutting plants for various combustible gases are the same as welding plants; only the construction of the torch is different. The cutting torch is a combination of the welding torch with a special feed for the cutting oxygen. The flame, in the portion which is made like a welding torch, heats up the article to the ignition temperature. The high pressure oxygen which flows out of another pipe carries out the cutting work. Every cutting torch, therefore, has two nozzles which are arranged one behind the other or concentrically. In the first case the preheating nozzle is situated in front of the cutting nozzle when viewed from the direction of cutting. In the second case the cutting nozzle surrounds the preheating nozzle concentrically. This arrangement has the advantage that, in cutting, the torch may be moved in any desired direction, and it is very easy to make curves with it, whereas, on cuts with the other type, the jet of oxygen in a "branch" or "two jet" torch comes out in such a way that it is deflected a little sideways, so that it makes a wide cut, and does not accurately impinge on the preheated spot. For this reason concentric jet torches have almost completely displaced the type where the nozzles are placed one behind the other, although special attention has to be paid to correct setting of the preheating flame with the former so that it does not exercise a carburizing effect. In the other type of construction this danger is not so likely to occur, since the heating flame is set back somewhat because of the clearance which is required. At the same time, the oxygen jet acts more efficiently because the corresponding exit nozzle can be brought much nearer to the work. This

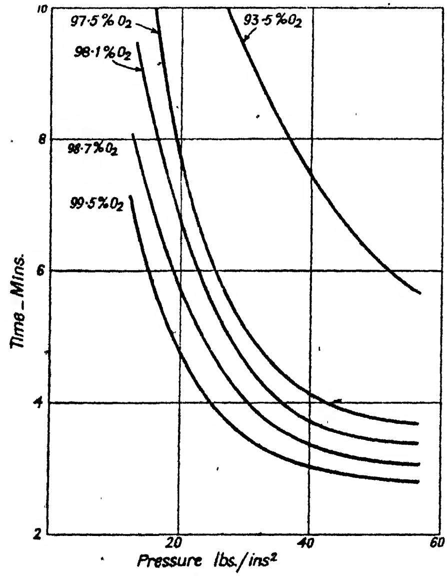


Fig. 1.—Time taken to cut the same length in gas cutting, depending on the working pressure, for various oxygen purities.

arrangement is impossible with the concentric jet torch, as otherwise the heating flame would melt the cutting nozzle. The drawback that, with the concentric jet torch, the preheating flame touches the article twice, should also be mentioned.

Since, apart from the combustible gas, oxygen has also to be led to the torch at different pressures for the purpose of combusting the gas as well as for cutting, various types of oxygen feeds were originally provided on the torch so that, including the hose for the gas, three hoses had to be connected. The gas, the oxygen for combustion, and the oxygen for cutting were led separately to the torch. For this purpose, the oxygen cylinder had a double reducing valve. Although this apparatus proved very satisfactory in service, one went over to the torch with two hoses since three hoses hindered the operator considerably. In one line the combustible gas is led to the torch and oxygen is led in a second. By means of a special valve, the oxygen required for the preheating flame may be tapped off. The torch with two hoses has the drawback that, during working, there is an interaction between the heating and cutting oxygen, which must be taken into account when setting the heating flame. With torches having two hoses, the flame should be set with excess oxygen since a reduction in the supply takes place when cutting oxygen is being used at the same time. For this reason, on cutting machines a return has been made to the torch with three hoses, since with this type there is no reason for limiting the number to two hoses, whereas for manual work the torch with two hoses has become predominant.

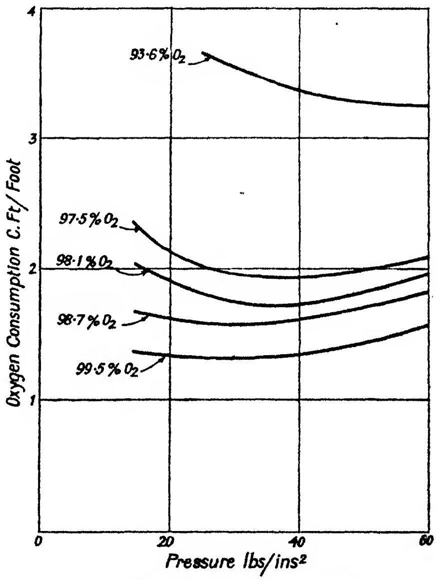


Fig. 2.—Oxygen consumption in gas cutting for various oxygen purities, depending on the working pressure.

In workshops where a lot of cutting is done, it is advisable, even more than with welding installations, to connect several cylinders together to form a central battery, or to arrange a central supply of oxygen, since the consumption of oxygen is high.

Depending on the kind of combustible gas which is used or the purpose for which it is used, some distinction must be made in the range of various types of cutting torches although they do not differ essentially from one another. On the one hand, we have cutting torches for acetylene, hydrogen, benzol, and illuminating gas. On the other hand, torches are constructed for longitudinal cutting, and for the following special purposes: hole cutting, rivet head removing, rivet shank removing, under water cutting, boiler tube

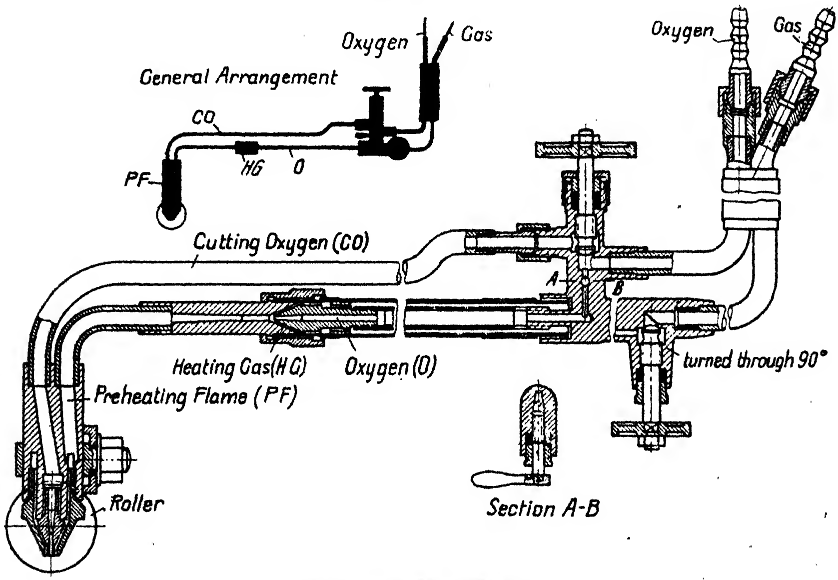


Fig. 3.—Concentric gas torch

cutting, and for cutting cast iron. In addition, welding and cutting torches are frequently combined in one design, and in this type a special cutting insert is provided for the cutting torch. A torch of this kind has already been shown in figs. 33 and 34, p. 50. Fig. 3 illustrates a concentric jet torch which is frequently used. If the ordinary type of design is unsuitable, the type of construction may be suitably modified. For example, on breakdown coaches, torches are made with an elongated handle and a long cutting head, in case work has to be carried out in corners which are difficult to get at. For work on stagings, for dismantling work, &c., one-handed torches are to be recommended, and these enable the torch to be handled, and, at the same time, enable one to open and shut the oxygen cutting valve with one hand.

A special design, which is widely used, is the rivet head torch, which is shown in fig. 4. It possesses a tip which is shaped like a

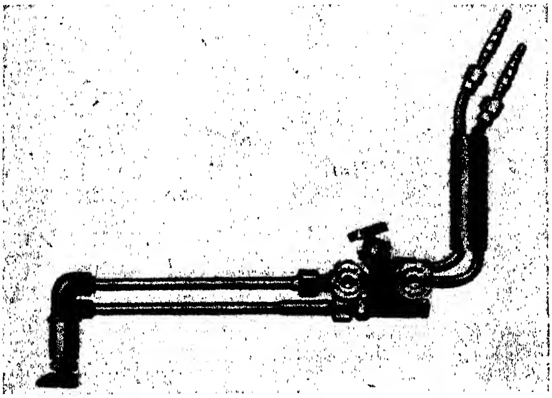


Fig. 4.—Rivet head torch

flat shoe. The preheating and cutting gas come out of two nozzles which are arranged alongside one another, and they pass out over

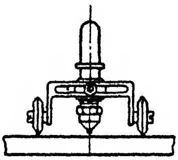


Fig. 5.—Carriage for vertical cuts

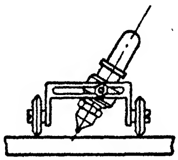


Fig. 6.—Carriage for bevel cutting

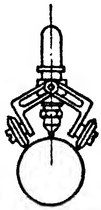


Fig. 7.—Twin carriage

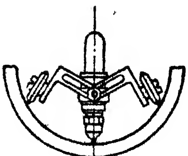


Fig. 8

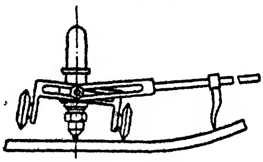


Fig. 9

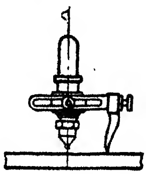


Fig. 10

Figs. 5–10.—Guide carriages for cutting torches

the riveted plate so that, when the rivet head is being cut off, the former is not damaged. The tip may be moved in all directions. In order to ensure that the nozzles of the torch during welding are always guided at a uniform distance from the work, which is necessary for ensuring the steady completion of the cut, normal torches

are supplied with guide rollers or a guide carriage which may be removed so that cutting may be carried out without them. Figs. 5–10 indicate a series of guide carriages of this type for various classes of work, provided with slot adjustment gear or the two link arrangement.

Another special type of construction is the under water cutting torch, which renders cutting under water possible. It is connected to four pipes through which compressed air must be fed in addition to cutting oxygen, heating oxygen, and the heating gas. By means of a powerful concentric jet of compressed air, water is forced away from the cutting surface, and both the preheating flame and the oxygen cutting flame are surrounded by a shield of air. The cutting process is otherwise similar to cutting in air. The deeper the work is done under water, the greater must be the working pressure to which the gas is adjusted.

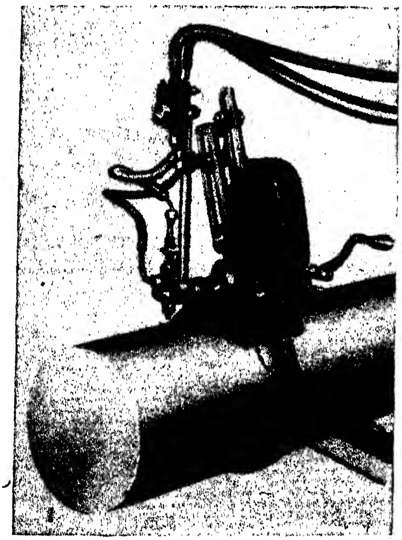


Fig. 11.—Shaft-cutting machine

Cutting Machines.—The more steadily the torch is guided the cleaner is the cut. Since moving the torch by hand is never done as regularly as in a machine, steps were taken a long time ago to construct cutting machines, since in addition to this advantage they possess the advantage of having a higher cutting output. The conditions for mechanical drive are much simpler for cutting than for welding. Consequently, cutting machines are to-day constructed so perfectly as to make it possible to cut out constructional members of all kinds so cleanly that subsequent machining is no longer necessary. The feed of the torch was first carried out on cutting machines by hand using a crank. The machines which are at present on the market are provided with electric motor drives throughout.

There are smaller machines which may be brought up to the work and larger fixed machines which can be employed satisfactorily where a large amount of work is done. In addition, special machines are constructed for definite purposes such as longitudinal cutting,

circular cutting, the cutting of shafts, the cutting of rolled sections, &c. A machine of this type is shown in fig. 11 (a shaft cutting machine). Accurate setting of the torch is achieved by means of a parallelogram guide. These machines to-day have also retained their field of application on work where cuts of the same type have to be carried out in large numbers. After machine cutting with machines had started in Germany, cutting with machines working with templates was adopted from other countries.

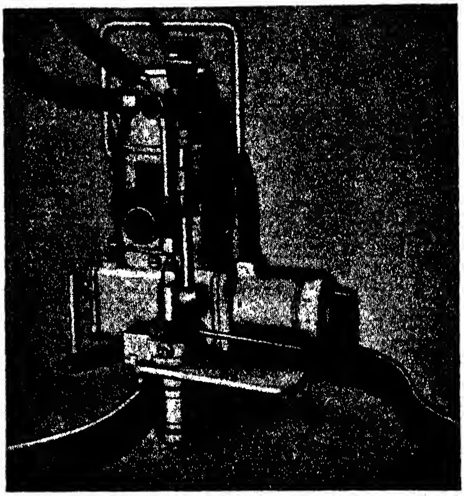


Fig. 12.—Curve-cutting machine

To-day excellent machines are also constructed in Germany which fulfil all requirements, and which at the same time make it possible to obtain cuts of all kinds in which the cut edges are extraordinarily clean. From the large number of

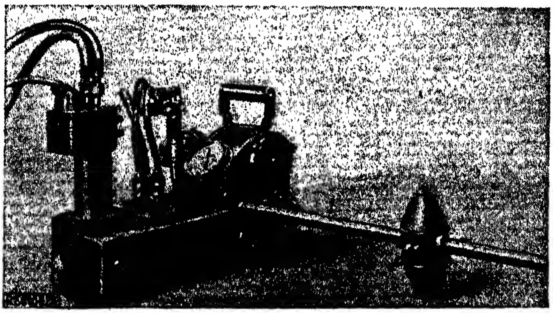


Fig. 13.—Hand-cutting machine "Secator"

machines, only a few examples can be mentioned. In general, reference must be made to the literature and to the publications of manufacturing firms.*

* Wiegand, "Advances in Autogenous Cutting". A paper given on the occasion of the Main Meeting of the V.D.I. (1930) in Vienna. Publication by the firm

Fig. 12 shows a curve cutting machine which runs on a template made from a bent strip and this may be used with success in the construction of boilers and containers.

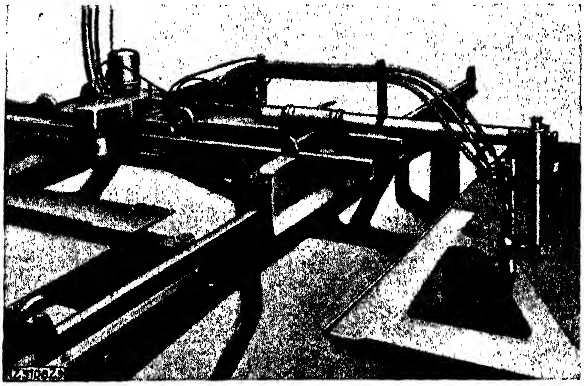


Fig. 14.—Automatic template cutting machine

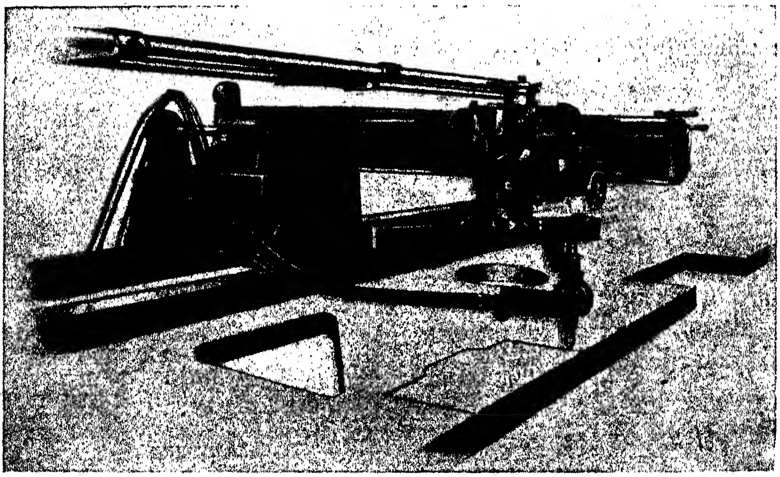


Fig. 15.—Universal cutting machine

Fig. 13 shows a cutting machine which is called the " Secator ". It may be guided on a drawing or a tracing and also on guide rails. In the same way bevel cuts for making edges for welding or caulking can be made on this machine, just as can be done on all guided machines.

Griesogen-Kalisch, " Gas Welding and Cutting Technology ", at the Leipzig Fair, 1930, *Schmelzschweissung*, Vol. 9, 1930, p. 99.

Whereas guiding of the machine on the type previously mentioned is usually carried out by hand, the template cutting machine for series and mass production work shown in fig. 14 is completely automatic. The cross carriage which carries the torch is guided along a template by means of a magnetic roller.

Finally, fig. 15 shows a fixed, large size, universal cutting machine of German construction.

The Cutting Process

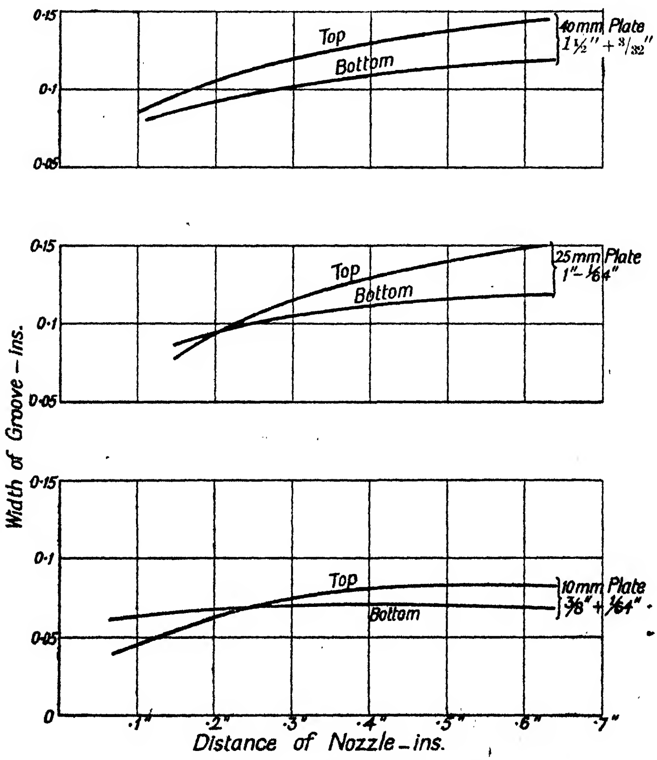
For cutting purposes, the combustible gas is first fed to the torch and ignited, after the preheating oxygen for the heating flame has been fed in. This is so adjusted that, for hydrogen, a short non-illuminating flame centre with a long bluish-yellow shielding flame is obtained, and with acetylene a short, sharply defined, bright illuminating central flame with a long non-illuminating surrounding flame may be seen. The preheating flame is then allowed to act on the article until this is brought up to white heat. Only then is the oxygen cutting valve opened and the cutting process begins. The start of the cut should always be made at the edge of the article. It is only when a cut is to be taken out of the middle of a complete plate that a hole is first burnt in the latter and the cut is started there. It is advisable, in this case, to fix a setting with a rather higher oxygen pressure and a somewhat softer preheating flame. The torch is kept quietly on the spot until the oxygen jet goes through.

As soon as the jet of oxygen begins to cut, the torch is slowly drawn forward. In this way the oxygen jet always impinges on a part which has been adequately preheated, so that continuous cutting takes place. Theoretically the heating flame could then be extinguished.

The preheating flame in the oxygen nozzle must always have an accurate constant distance from the cut surface. With material thicknesses of $\frac{1}{8}$ in. to $2\frac{1}{4}$ in. this distance should be $\frac{1}{8}$ to $\frac{3}{16}$ in. With thicknesses of $2\frac{1}{4}$ to $5\frac{1}{2}$ in., about $\frac{3}{16}$ in. to $\frac{1}{4}$ in., and greater than this, $\frac{1}{4}$ to $\frac{3}{8}$ in. If guide rollers or guide carriages are used, they are initially set to give this distance. Using the wrong distance with the torch leads to variation in the width of the cut; as the distance increases, the width is increased. Figs. 16 to 18 show to what extent this is the case.

If the heating flame is adjusted too large, the upper layer is fused,

and with hydrogen, decarburization of the cut surface takes place. Acetylene, on the other hand, often has the effect of carburizing the iron through the whole depth of the cut. In both cases we get irregular cut edges. The effect of having too large a heating flame is very great with concentric jet torches in which the flame acts for a longer time on the molten metal. Even with a normally adjusted flame these



Figs. 16–18.—Width of groove for various distances of the nozzle from the job

effects are present. They are, however, so insignificant that, as a rule, the cut edges do not experience any harmful change in crystal structure.

The torch must be held steady. An irregular feed of the torch results in unclean cuts. In order that the guiding of the torch should not tire the welder, he should, where possible, support it with his free hand and draw it towards him. The cutting speed is governed by the thickness of the article and the experience of the welder. If the thickness is too great, cutting stops. The cutting oxygen must

then be turned off and the article must be reheated up to white heat. If the flame strikes back, all the valves on the torch must be immediately shut. The tip is then cooled in water before cutting is started again. If the cutting work is interrupted for any reason, the oxygen valve should be closed for reasons of economy.

Rolled sections cannot be cut through in one cut. In these circumstances, it is necessary to start the cut many times from the outer edges; for example, on angle irons it has to be done twice Cutting through several plates laid one over the other cannot be done in one cut, since one is faced with too high an insulating effect; the plates must be cut one after the other, a wider groove being cut in the upper one through which the next one may be reached.

In the same way as with an irregular guiding of the torch, or by an incorrect adjustment of the flame, dirtiness of the nozzles results in an irregular cut (see figs. 19 to 22). Dirty nozzles may also lead to back fires.

Fig. 19.—Dirty nozzle

Fig. 20.—Irregular forward travel

Fig. 21.—Too big a heating flame

Fig. 22.—Good cut

Figs. 19–22.—Good and bad gas cuts

The Use of Gas Cutting.—Just as welding was only initially used for repair work, the cutting torch, in the very early days, was used for dismantling work during breaking up and scrapping. In this field it has become an indispensable tool since there is no other process which is as cheap. Whereas in welding engineering, a change to initial manufacture, in various fields, only took place relatively late, the cutting torch was used for fabricating and cutting new members very shortly after its introduction. If it is borne in mind that, although straight cuts can be made with shears and saws on plates, round bar, and sections, but that cutting-out work, slotting, or circular cuts cannot be made with this equipment, and that when work of this kind is done without the cutting torch one has to employ drilling and milling, it is easy to see how great an economic advance in technology was afforded by the discovery of the cutting torch.

In spite of this, the use of the cutting torch was, up to a short time ago, limited by official regulations and manufacturing specifications, so that the economic advantages of this process could not then be completely employed. It was assumed that the material changes which were set up by the heating effect during gas cutting at the cut edges would cause cracks in the material. Even after the production of perfectly smooth cuts was made possible by the introduction of the cutting machine, so that notch effects which might be started at a groove of a hand cut were eliminated, the regulations were not at first changed. Gas cutting was either entirely forbidden, as for example in steam boiler construction in which the making of edges for caulking was not allowed by gas cutting, or at least it was laid down that the cut edges had to be subsequently machined either by planing, milling, turning or chiselling, so that the layer which had been affected was removed for a sufficient distance. Opinions differed in regard to how deep the influence of the heating goes and what this influence at various depths is.

What exactly the state of affairs in this respect is was cleared up recently by comprehensive tests carried out by the Research Laboratories at the I. G. Farbenindustrie A.G. Griesheim.* Experiments cover not only the ordinary constructional steels, but also alloy steels and a comparison with other forms of working. In order to clear up the matter further Der Fachauschuss für Schweisstechnik (Technical Committee for Welding Technology) has collected material from the Studienauschuss für hochwertigen Baustahl (Committee for the Study of High Grade Constructional Steels), from the German State Railways Co. and from the Technical High School, Charlottenburg, who had also been occupying themselves with tests in this direction.†

It was established metallurgically that, in a gas cut, three zones which may be distinguished from one another stand out more or less clearly. Fig. 23 shows this. In the external zone *a* at the edge, a coarse grained structure is clearly indicated, and according to the composition of the material, this shows evidence of separation or aggregation. In the middle zone *b*, there is a normalized structure from which the regular distribution of carbon in the steel may be

* "Autogenous Cutting of Structural Alloy Steels". Communication from the Research Laboratories Autogenous Workshops of the I. G. Farbenindustrie A. G., Frankfurt-Griesheim. Printed as a manuscript.

† Hilpert, "Material Changes in Structural Steel Worked with a Cutting Torch". Report prepared by the Technical Committee for Welding Technology of the V.D.I., Vol. 75 (1931), p. 649.

seen. The fine grained structure extends further the more rapid is the cooling of the cut surface. It also depends on the material thickness. Finally, in the third zone *c*, a change to the structure of the material takes place. Depending on the class of material, the effective depth from the tests was as follows. For the zone *a*, ·008 to ·022 in.; for the zone *b*, ·008 to ·051 in.; for the zone *c*, ·008 to ·021 in. The total zone affected was never greater than $\frac{5}{64}$ in. Without going further into the matter, we see that specifications which called for a machining of the gas cut for a depth of at least $\frac{3}{8}$ in. go far beyond what is necessary.

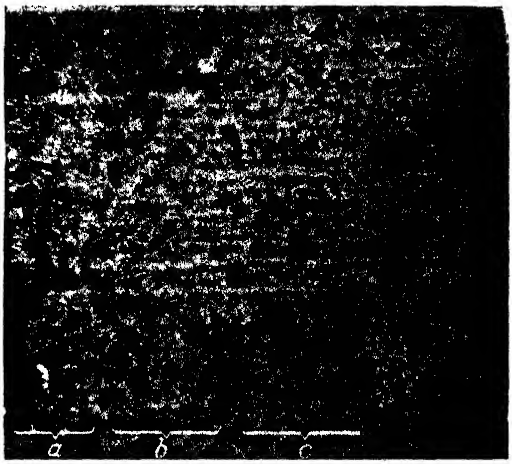


Fig. 23.—Micro-photograph of a gas cut. 100 magnifications.

a, *b*, *c*, influence zones.

Experiments were not limited to a metallurgical investigation. In order to clear up the matter further as to how parts which were made by gas cutting behaved under working stresses, tensile and bend tests were put in hand both on ordinary structural steel and on high alloy steels. The tensile tests showed a somewhat higher strength with a somewhat lower ductility as compared with unworked steel. The deformation capacity remained the same. The bend tests showed in every case angles of bend to 180° without fracture, with very few exceptions, and these could not be put down to the gas cutting process. On the other hand, with another series of tests on sheared cuts, serious cracking occurred which could be seen with the naked eye. In general, it was established that the edge effect due to squeezing and deforming the material was much greater

and more seriously affected the use of the members, on members which had been manufactured by mechanical methods, than on parts which had been made by gas cutting.

It may, therefore, be assumed that the regulations which limit the use of gas cutting will be removed in future, as has happened to some extent, and that the unrestricted application of this process, which is the cheapest of all cutting methods, will be granted. This will be a great advantage, especially for welding technology, since cutting of the members to be welded, using a gas cut, a process which has already widely established itself, will reduce the costs of manufacture in all cases. In addition, gas cutting will contribute considerably to increased economy in other fields, as for example in

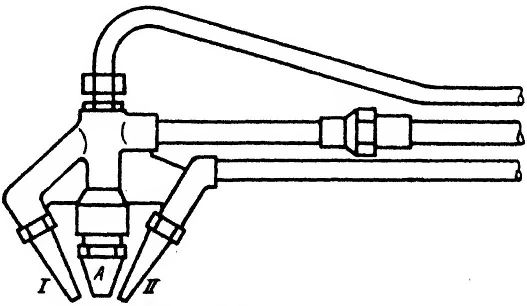


Fig. 24.—Cast-iron cutting torch

I, II, Auxiliary nozzles; *A*, preheating and cutting nozzle.

steam boiler construction, container construction, shipbuilding, in which it can replace parts which were previously forged by parts which are cut from the solid. In addition, it may be assumed from the tests, which have previously been described, that cutting can be adopted without any reduction in quality. At the same time, it must be admitted that gas cuts occasionally do not give a perfectly smooth cut edge, especially on long cuts, or on high alloyed or high carbon materials, because of irregular composition, and also because of the presence of segregation zones. A certain amount of care should therefore be exercised, and the result of tests dealing with these special cases should be watched. Gas cuts on springs, from a material of 50 tons/in.^{2} tensile strength have completely fulfilled all expectations, so that it is intended to employ them without further question. Additional experience will create new fields of application for gas cutting.

The Gas Cutting of Cast Iron.—As was previously pointed out,

gas cutting is only applicable to steel. A cutting process has certainly been worked out for cast iron, but strictly speaking, it is a smelting process. It has not acquired the importance of steel cutting, since it can only be considered for dismantling work. At the same time, it may introduce considerable simplification in the scrapping of blocks of cast iron. In conclusion, therefore, it will be discussed briefly.

The reasons why cast iron cannot be easily cut are to be found in the reasons which have already been discussed. There have been successful attempts in making cast iron so that it could be gas cut by melting down steel wire into the cut groove, so that the cast iron acquired the characteristics of steel at the point of cutting. The process, however, did not yield very satisfactory results. Recently Kalisch * has taken up this process again with more success. He went about it in the following way. The cut edge was preheated to red heat, and then the filler material, which was used for the fusing process, was brought quickly up to the edge. Simultaneously the same movement was carried out with the torch. The filler rod and the torch were removed for a short time, and then the portion at the edge, which now had a lower carbon content, was burnt away by bringing up the flame once more.

Up to a few years ago, the cast iron cutting torch, illustrated in fig. 24, was in most general use. In addition to the concentric preheating and cutting nozzle *A*, it possesses a supplementary nozzle *I* and *II* situated before and behind the former. Through the combined effect of the three flames, a considerable portion of the molten iron is oxidized and a very much quicker and smoother cut can be obtained than with the ordinary cutting torch.

The edge of a cast iron cut is not as narrow and smooth with either of the two processes as in the cutting of steel, but as a rule it fulfils all the requirements which can be asked of it.

* Kalisch, " Recent Investigations into the Gas Cutting of Cast Iron ", *Autogene Metallbearbeitung*, Vol. 23 (1930), p. 15.

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